AD629783

TECHNICAL REPORT

THEORETICAL PREDICTION OF THE FLOW IN THE WAKE OF A HELICOPTER ROTOR

PART 2 - FORMULATION AND APPLICATION OF THE ROTOR-WAKE-FLOW COMPUTER PROGRAM

By: Peter Crimi

CAL No. BB-1994-S-2

Prepared for:

U.S. Army
Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland 21005

Final Report - Part 2
Contract No. DA30-069-AMC-645(R)
September 1965

Cod - 1

Microfiche

8.60 0.75 82

CORNELL AERONAUTICAL LABORATORY, INC.
OF CORNELL UNIVERSITY, BUFFALO, N. Y. 14221

DISCLAIMER NOTICE

THIS DOCUMENT IS BEST QUALITY PRACTICABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

CORNELL AERONAUTICAL LABORATORY, INC.
BUFFALO, NEW YORK 14221

THEORETICAL PREDICTION OF THE FLOW IN THE WAKE OF A HELICOPTER ROTOR

PART 2
FORMULATION AND APPLICATION OF THE ROTOR-WAKE-FLOW COMPUTER PROGRAM

By:
PETER CRIMI

CAL NO. BB-1994-S-2

FINAL REPORT - PART 2
CONTRACT NO. DA30-069-AMC-645 (R)

SEPTEMBER 1965

Prepared for:
U.S. ARMY
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND 21005

SUMMARY

As part of a study carried out at Cornell Aeronautical Laboratory for the U. S. Army (Contract No. DA-30-069-AMC-645(R)), two digital computer programs were prepared which direct the calculation of the time-varying flow in the vicinity of a helicopter rotor in forward or hovering flight. Fuselage interference effects are taken into account. The applicability of these programs to specific problems and procedures for their use are the subjects treated here.

First, the assumptions made in constructing the mathematical model and the relationship of the model to the physical flow are outlined. In this connection, the assumptions necessary for numerical analysis and the functional structure of the programs are also given.

Then, the formulations which were coded are presented. Included in the formulations are the coordinate identifications used and the definitions of program variables.

Finally, the procedures for implementation of the programs are given. The relationship of input quantities to aircraft flight parameters, program accuracy and computer running time are specified. A sample calculation, including both inputs and outputs, is presented. Program listings and operational information related to the programs are given in appendices.

FOREWORD

The work reported herein, performed between September 1964 and September 1965, was accomplished by the Cornell Aeronautical Laboratory, Inc. (CAL), Buffalo, New York for the Director of Ballistic Research Laboratories, (BRL) Aberdeen Proving Ground, Maryland. The research effort was performed under Contract DA 30-069-AMC-645(R) and was monitored for BRL by Mr. Thomas Coyle as Technical Supervisor. Dr. Peter Crimi of CAL conducted the study and received assistance from Mr. Alexander Sowydra during the development of the mathematical model and Mr. Harvey Selib for the digital computer programming.

This document is Part 2 of the final report under the contract. It describes the formulation and application of the rotor-wake flow computer program and is of use primarily to those who plan to use the digital computing program. Part 1 of the final report describes the development of the theory, discusses the results of the computation, and provides a comprehensive discussion of the work performed under the contract.

CAL Report Numbers have been assigned as follows:

BB-1994-S-1, THEORETICAL PREDICTION OF THE FLOW IN THE WAKE OF A HELICOPTER ROTOR, Part 1 - Development of Theory and Results of Computations

BB-1994-S-2, THEORETICAL PREDICTION OF THE FLOW IN THE WAKE OF A HELICOPTER ROTOR, Part 2 - Formulation and Application of the Rotor Wake Flow Computer Programs

CONTENTS

	Page

1. INTRODUCTION

A study was carried out at Cornell Aeronautical Laboratory for the U. S. Army (Contract No. DA 30-069-AMC-645(R)) with the objective of developing a theory for the prediction of the flow field in the wake of a helicopter rotor. As a part of this study, two digital computer programs were prepared which incorporate the analytical models derived. Given the flight conditions and geometric configuration of the aircraft, the programs direct the computation of the time-varying flow at arbitrary points in the wake of a translating rotor. Account is taken of fuselage interference effects.

This report is intended to provide the information which would be of use to technical personnel who have need of the data which these programs supply. An outline of the mathematical models used, the major simplifying assumptions applied and the relationship of the mathematical model to the physical flow are given so that the user may determine the applicability of the program to his particular problem. In addition, the equations which were coded are given and the necessary inputs are listed together with their relationship to flight conditions and their effect on running time and overall accuracy. The latter information will allow the user to convey to a computer programmer sufficient data to implement the programs in the manner desired.

No attempt has been made here to present rigorous derivations or complete justifications for the formulations given and assumptions made. The intention rather is only to provide sufficient information concerning the model so that its limitations and applicability are made clear. The complete derivation of the theory which the computer programs implement is reported in Reference 1.

The information necessary for the physical operation of the programs is given in Appendices I and II. Included there are program restrictions, usage, data preparation, and coding information.

2. THE MATHEMATICAL MODEL

DISCUSSION OF THE PHYSICAL FLOW

It is desired to define analytically the flow in the vicinity of a helicopter in translational or hovering flight out of ground effect. Consideration is limited to craft having a single rotor with from one to four blades.

There are three primary contributions to the flow at a given point relative to the aircraft. Specifically, the rotor blades, the wake of the rotor blades, and the fuselage all affect the air velocity. These three effects are interrelated in a highly nonlinear manner. The lifting blades induce a flow on their wake, causing the wake to distort. The distorted wake induces a flow on the blades, altering their loading, the two combine to affect the flow about the fuselage, and the fuselage in turn affects the blade loading and wake displacement.

The blades may be regarded as wings of very high aspect ratio in a free stream which is varying harmonically in time. The wake is generated by the blades as a thin sheet of vortical fluid. This sheet has been observed to roll up very rapidly into a pair of vortices (see Reference 2) so that except for the region a few chord-lengths behind the blade, it appears that each blade has trailing from it two vortices, one from the vicinity of the tip and one from the root. Smoke pictures (Reference 2) and the results of an analytical treatment of the wake of a hovering rotor (Reference 3) indicate that the root vortices are rapidly swept up through the center of the rotor plane and then dissipated. The root vortices, therefore, contribute very little to the flow. The smoke pictures also indicate that the tip vortices are quite stable and experience very little viscous dissipation, sustaining themselves for several rotor revolutions.

From the point of view of the fuselage and/or any nonlifting appendages, the flow appears as the superposition of a steady free stream caused by the translation of the aircraft and the periodic flow induced by the rotor and its wake. The contribution of the fuselage to the flow at any point is essentially that due to a body of complicated geometry in unsteady potential flow.

THE MODEL FOR THE ROTOR

A wing of high aspect ratio may be mathematically represented, to a very good approximation, by a line vortex with a spanwise variation of circulation such as to produce the proper variation of lift in the spanwise direction (see, for example, Reference 4). Each rotor blade has, therefore, been replaced by a line vortex with one end located at the position of the rotor hub and the other at the position of the blade tip. It has been assumed in adopting this model that the fluid is inviscid and incompressible. This assumption has also been made in formulating the models for the wake and fuselage.

A rigorous treatment of the blade effects would include the specification of radial and azimuthal variation of the circulation about these blade vortices in terms of the blade geometry, the blade motions, and the flow induced by the wake and fuselage. However, it is known a priori that the circulation does not vary substantially in the radial direction and that it varies azimuthally in such a way as to provide nearly a constant lift. Insofar as the blades affect the flow, then, they may be well represented by varying the circulation sinusoidally so as to produce nearly a constant lift and by taking the circulation as constant in the radial direction. This representation of the rotor has been adopted, with the total lift produced by the vortices made to equal the weight of the aircraft.

THE MODEL FOR THE WAKE

Since the wake of a rotor has been observed to consist primarily of vortices emanating from near the tip of each blade, the wake is represented by potential vortices, one originating from the tip of each blade vortex, which terminate at some arbitrary point far downstream. The circulation about a wake vortex in the physical flow at any given point is simply related to the circulation about the blade when it generated that portion of the wake. Consistent with that relationship, the circulation about the model of a wake vortex at any point is prescribed to be that which the vortex representing the blade had when it produced that wake element.

As a segment of a wake vortex is generated at the tip of a blade vortex when the blade vortex rotates and translates, a corresponding segment is discarded at the downstream end of the vortex. In this manner, the program is not encumbered by a wake of ever increasing size, while the essential structure of the wake is retained.

It should be noted that the positions of the wake vortices are not known a priori. The positioning of the wake is a function of the spatial and azimuthal variations of the flow, which in turn depend on the wake geometry itself. The location of the wake vortices, in fact, constitutes the primary function of the program. Once the wake has been located, at a given instant, the flow at any arbitrary point is completely defined and may be computed in a straightforward manner.

An enormous simplification would, of course, result if the wake geometry were prescribed by using some plausible assumption. This, in fact, has been done in a number of analyses and useful results obtained. For example, the time-varying flow in the rotor plane (Reference 5) and an indication of the spatial distribution of the time-average of the downwash (Reference 6) have been obtained in this manner. However, this program has as its objective the accurate prediction of the time-varying flow at arbitrary locations in the vicinity of the aircraft; wake distortions are a major factor in defining this flow, and can neither be neglected nor assumed known without introducing unacceptably large errors.

Also, it should be noted that the wake vortices must be assumed to have a small but finite core of rotational fluid (which, in fact, a physical vortex must have) even though the flow external to this core is precisely that due to a simple potential vortex having an infinite velocity at its center. This assumption is necessary because, if the wake is to be allowed to convect under its own influence, then the effect of immediately adjacent wake elements on a wake vortex must be computed. If a simple potential representation were used, infinite velocities of convection would then be predicted throughout the wake. On the other hand, the so called self-induced (i. e., locally induced)

fluid velocity acting on a finite-core vortex may be obtained in terms of the local curvature of the vortex and its core radius. The expressions for this velocity have been incorporated in the program.

The size of the core of a physical vortex is related to the kinetic energy in the flow. This relationship may be utilized to provide a rational means for computing the core size of the wake vortices for the model. This was done, and computations were performed which revealed that core size is relatively insensitive to flight conditions or blade azimuth and that a value for core radius of five percent of a rotor radius may be utilized for all flight conditions without introducing significant errors.

Core size may change significantly due to stretching of wake vortices; the volume of the rotational core must remain constant in an inviscid flow. This effect has been taken into account in the formulation.

THE MODEL FOR THE FUSELAGE

The fuselage is represented as though it were immersed in a uniform free stream of constant magnitude and direction. The assumed free stream consists of two components, one being the negative of the velocity of translation of the aircraft, and the other being a time and spatial average of the downwash induced by the rotor and its wake. The latter component may be computed by temporarily omitting the fuselage representation from the program and evaluating the desired averages where the fuselage is located.

At high forward speed, the time and spacial variations of the stream experienced by the fuselage are small, and so may be neglected without causing large errors. At low forward speed the flow over the fuselage does vary substantially, but the total effect of the fuselage is then small in comparison with wake and rotor-induced effects, and so the error is again not appreciable.

Since, in general, the geometry of a helicopter fuselage cannot be adequately described analytically, neither can the flow about the fuselage be represented in simple closed form. However, assuming that the fluid is both incompressible

and inviscid, which it very nearly is, the potential flow about a nonlifting body may always be represented by replacing the body by a surface distribution of potential sources having spacially varying strength (see Reference 7). This representation has been used to compute the effect of the fuselage on the flow.

ASSUMPTIONS FOR NUMERICAL ANALYSIS

The models of the rotor blades, the wake, and the fuselage described above may, at least in general terms, be formulated as continuous functions of time and spacial coordinates. A digital computer cannot, of course, continuously integrate continuous functions. Therefore, step-wise and interpolative approximations have been made.

A rectangular integration scheme is used in performing integrations in time. That is, when integrating velocity to compute displacement, the velocity is assumed to remain constant over an interval of time corresponding to a small finite change in the azimuth position of the blades.

Spacial integrations over the wake vortices are performed by assuming that these vortices are made up of small rectilinear vortex segments whose circulation is constant from one end point to the next. The position of the wake is then defined by the locations of the end points of these segments. Consistent with the approximation made in the time integration, the initial length of each wake segment is the length of the arc swept out by the blade tip over the interval used for time integration. Self-induced effects at a given wake point are computed by taking, as the local curvature, the reciprocal of the radius of the circle passing through the wake point in question and the two wake points adjacent to it.

The surface of the fuselage has been replaced by a set of plane quadrilateral source sheets. The source strength per unit area for a given sheet is assumed to be uniform over the sheet. The determination of these strengths may be separated from the actual computation of the flow, and is accomplished

with a separate computer program. The output of the latter program then forms part of the input to the main program.

FUNCTIONAL STRUCTURE OF THE PROGRAMS

The Main Program

The program modeling the rotor, the wake and the fuselage has been constructed to form a numerical analogue to the physical flow. Given an initial wake geometry and aircraft flight conditions, it proceeds to integrate in time, convecting the wake according to the analytical prescriptions described above. The process will continue through as many rotor revolutions as desired. It has been found that generally a periodic flow is eventually established after which, of course, no further information can be obtained by continuing the computations. A criterion has been found for choosing a number of rotor revolutions sufficient for the establishment of a periodic flow. This criterion is given in the discussion of program implementation.

As the computations proceed, the wake configuration, as well as fluid velocities at any points desired, at a given instant (i. e., azimuth position) are stored on tape. This information is relinquished as output upon completion of computations.

The flow of information as computations proceed is represented schematically in Figure 1.

The Supplemental Fuselage Program

As noted previously, the function of the supplemental fuselage program is to determine the strengths of the source sheets representing the fuselage. The procedure used is based on the method reported in Reference 8. The program is given the locations of the quadrilaterals representing the fuselage surface. It is then required that the combined effe' cs of the free stream and the sum of source-induced velocities be such that the fluid velocity normal to each element be zero. This requirement provides a set of linear algebraic

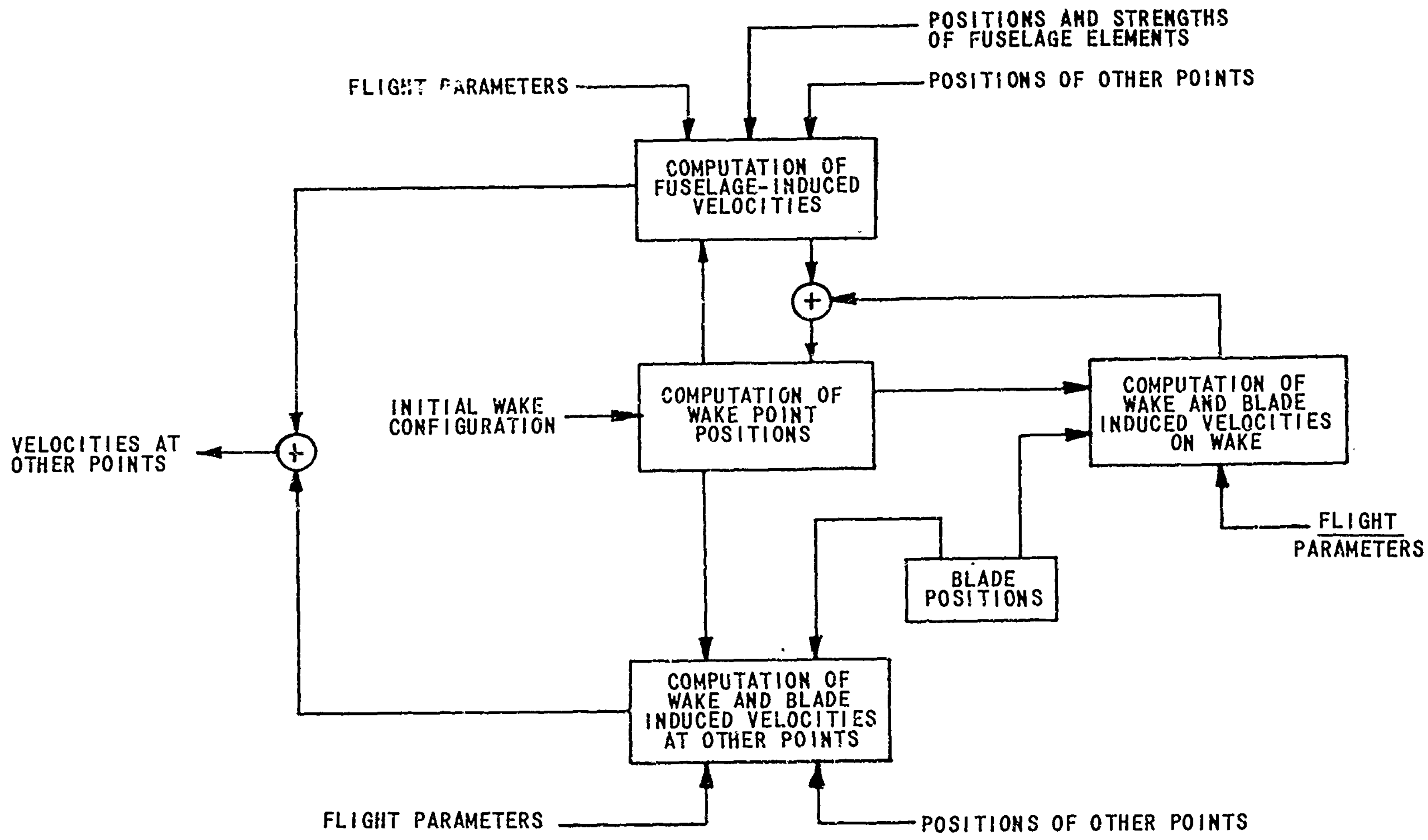

Figure 1 SCHEMATIC DIAGRAM OF THE FLOW OF INFORMATION FOR THE MAIN PROGRAM

equations with the source strengths as unknowns. The fuselage program computes the coefficients for this set of equations and then solves them, using a simple iterative procedure. The strengths and related geometric parameters are the outputs, which are then used as inputs to the main program.

3. FORMULATIONS FOR THE MAIN PROGRAM

In the following sections, the equations are given which were coded for the main program. All distances have been nondimensionalized by rotor radius R and velocities by rotor tip speed ΩR, where Ω is the angular velocity of the rotor.

COORDINATE IDENTIFICATIONS AND NOMENCLATURE

Rotor and Rotor Wake

A coordinate system fixed in the tip-path-plane of the rotor is used. The model for a two-bladed rotor and its wake is shown in Figure 2. As noted on the figure, a free stream of dimensionless magnitude μ is directed at an angle α_T to the tip-path-plane and parallel to the x-z plane. The azimuth position ψ of the rotor is defined to be the angle between blade vortex 1 and the x-axis, as shown (blade numbers increase in a counterclockwise direction when the rotor is viewed from above). The points P_{ij} are the wake reference points; the first subscript, i , increases successively proceeding down the wake vortex for a given blade, and the second subscript, j , denotes the number of the blade which generated that wake vortex. Each wake segment is associated with that end point having the lower first subscript. For example, the element between points P_{22} and P_{32} is denoted as element (2, 2). Each element (i,j) is assigned a dimensionless core radius a_{ij} and strength Γ_{ij} . For convenience in computation, the latter quantity has been normalized by the average circulation about the blade vortices.

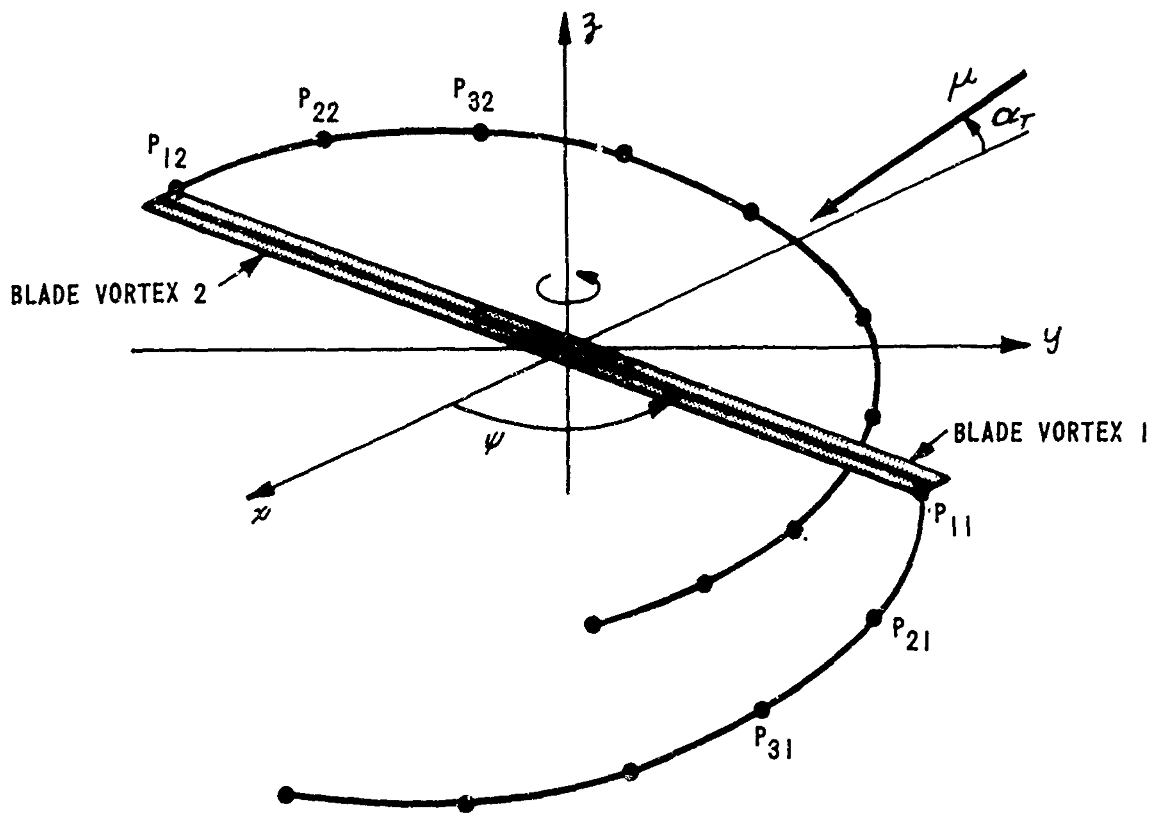

Figure 2 MODEL FOR THE ROTOR AND WAKE

Fuselage

The model of the fuselage is referred to the same coordinate system as is that of the rotor and its wake. The surface representing the fuselage is shown schematically in Figure 3, with a few representative source-sheet elements outlined.

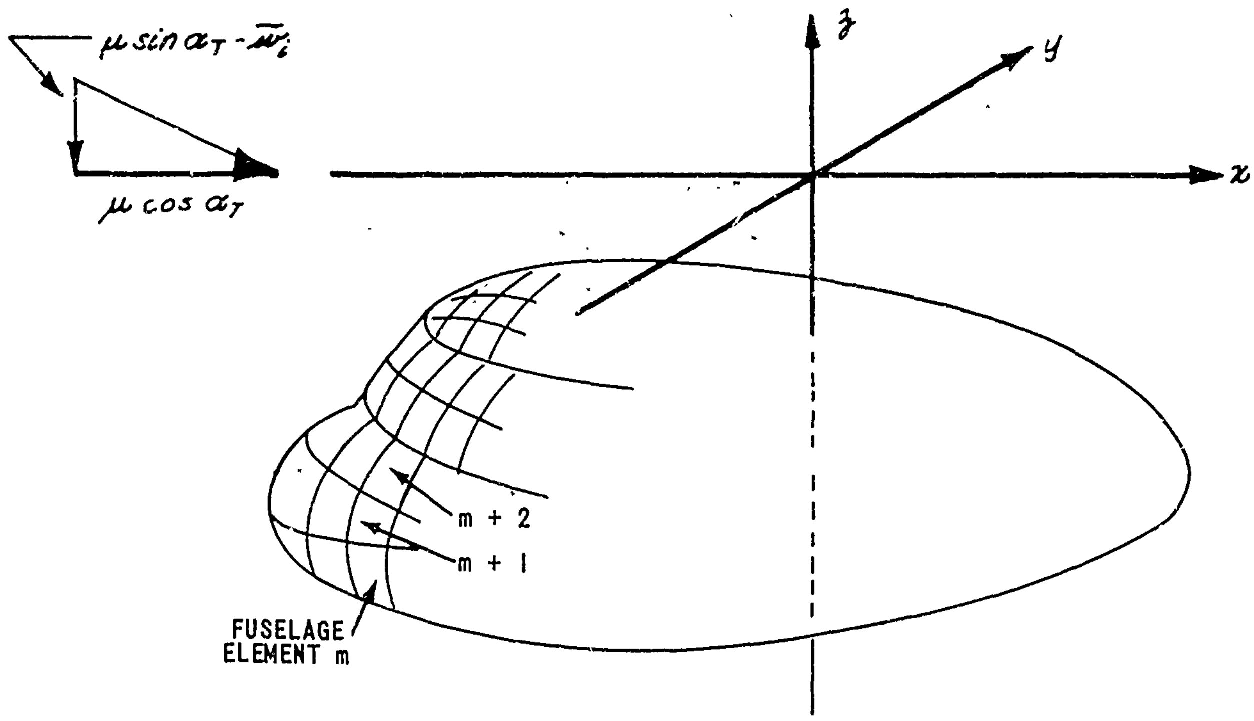

Figure 3 SCHEMATIC REPRESENTATION OF FUSELAGE MODEL

The fuselage is assumed to be subjected to a uniform free stream with x-component $\mu \cos \alpha_T$ and z-component $\bar{w}_i - \mu \sin \alpha_T$, where $\bar{w}_i$ is a time and spacial average of rotor and wake-induced velocities acting on the fuselage in the z-direction. The fuselage has been assumed to be symmetric about the x-z plane, so that only half of the fuselage need be considered. The source elements are numbered consecutively from $m = 1$ to $m = N_f$, where N_f is the number of fuselage elements representing (half of) the fuselage. Each fuselage element has its vertices numbered (from one to four) in clockwise fashion when viewed from the exterior of the fuselage.

Associated with each fuselage element m are the normalized source strengths σ_{x_m} and σ_{z_m}. The total source strength of element m is thus

$$\mu \cos \alpha_T \sigma_{x_m} + (\bar{w}_i - \mu \sin \alpha_T) \sigma_{z_m}$$

The quantities σ_{x_m} and σ_{z_m} are computed by the supplemental fuselage program, as described in Formulations For The Supplementary Fuselage Program. Certain other quantities are also obtained from the supplemental fuselage program and used as inputs to the main program. These quantities define the position and orientation of the elements. Their definitions are given in Formulations For The Supplementary Fuselage Program.

EQUATIONS FOR COMPUTING DISPLACEMENTS AND VELOCITIES

General Equations

Let $v_x(x, y, z, \psi)$, $v_y(x, y, z, \psi)$ and $v_z(x, y, z, \psi)$ denote the dimensionless components of fluid velocity at point (x, y, z) for the rotor at azimuth position ψ. Then if (x_{ij}, y_{ij}, z_{ij}) denote the coordinates of vortex end point P_{ij}, the wake displacement is given by

$$x_{ij}(\psi+\Delta\psi) = x_{i-1,j}(\psi) + v_x(x_{i-1,j}, y_{i-1,j}, z_{i-1,j}, \psi)\Delta\psi$$

$$y_{ij}(\psi+\Delta\psi) = y_{i-1,j}(\psi) + v_y(x_{i-1,j}, y_{i-1,j}, z_{i-1,j}, \psi)\Delta\psi$$

$$z_{ij}(\psi+\Delta\psi) = z_{i-1,j}(\psi) + v_z(x_{i-1,j}, y_{i-1,j}, z_{i-1,j}, \psi)\Delta\psi \qquad (1)$$

for $\qquad i = 2, 3, \cdots, N_W + 1$

and $\qquad j = 1, 2, \cdots, N_B$.

The integers N_B and N_W denote, respectively, the number of blades and the number of wake elements per blade included in the calculation, and $\Delta\psi$ is the incremental change in blade azimuth position:

$$\Delta\psi = \frac{2\pi}{N_A}$$

$$N_W = N_R N_A$$

where N_A is an integer, being the number of azimuth stations into which the rotor plane is divided, and N_R is the number of revolutions of wake per blade taken into account.

The wake and blade reference points not determined through equations (1), namely P_{0j} and P_{1j}, are simply located according to

$$x_{0j}(\psi) = y_{0j}(\psi) = z_{0j}(\psi) = 0$$

$$x_{1j}(\psi) = \cos\left[\psi + \frac{2\pi}{N_B}(j-1)\right]$$

$$y_{1j}(\psi) = \sin\left[\psi + \frac{2\pi}{N_B}(j-1)\right] \qquad (2)$$

$$z_{1j}(\psi) = 0$$

for $\qquad j = 1, 2, \cdots, N_B$.

The fluid velocity components at a point (x, y, z) needed in Equations (1) and in the definition of the flow at an arbitrary point, may be broken down as follows:

$$\frac{1}{\lambda} v_x(x,y,z) \equiv V_x(x,y,z) = \frac{\mu}{\lambda}\cos\alpha_T + V_{w_x}(x,y,z) + V_{f_x}(x,y,z)$$

$$\frac{1}{\lambda} v_y(x,y,z) \equiv V_y(x,y,z) = V_{w_y}(x,y,z) + V_{f_y}(x,y,z) \tag{3}$$

$$\frac{1}{\lambda} v_z(x,y,z) \equiv V_z(x,y,z) = -\frac{\mu}{\lambda}\sin\alpha_T + V_{w_z}(x,y,z) + V_{f_z}(x,y,z)$$

where λ is an input parameter which relates directly to the thrust on the rotor (see Procedure For Implementation Of The Programs), V_{w_x}, V_{w_y} and V_{w_z} are the contributions of the wake and blade vortices and V_{f_x}, V_{f_y} and V_{f_z} are the contributions of the fuselage source sheets.

The strengths and core sizes of the wake elements for azimuth position $\psi+\Delta\psi$ are assigned in terms of inputs and their values at azimuth position ψ. Specifically, the strengths are given by

$$\begin{aligned} \Gamma_{ij}(\psi+\Delta\psi) &= \Gamma_{i-1,j}(\psi), \qquad \begin{cases} i = 2, 3, \cdots, N_W \\ j = 1, 2, \cdots, N_B \end{cases} \\ \Gamma_{1j}(\psi+\Delta\psi) &= \frac{1}{2}\left[\Gamma_{B_j}(\psi) + \Gamma_{B_j}(\psi+\Delta\psi)\right], \quad j = 1, 2, \cdots, N_B \end{aligned} \tag{4}$$

where Γ_{B_j} is the strength of blade element j. The strength of blade element 1 at each azimuth is specified as an input, while

$$\Gamma_{B_j}(\psi) = \Gamma_{B_1}\left[\psi + (j-1)\frac{2\pi}{N_B}\right], \qquad j = 2, 3, \cdots, N_B \tag{5}$$

and, of course,

$$\Gamma_{B_j}(\psi + 2\pi) = \Gamma_{B_j}(\psi).$$

The core sizes are assigned according to

$$a_{ij}(\psi+\Delta\psi) = \left[\frac{L_{i-1,j}(\psi)}{L_{ij}(\psi+\Delta\psi)}\right]^{1/2} a_{i-1,j}(\psi) \tag{6}$$

$$\text{for} \quad \begin{aligned} i &= 2, 3, \cdots, N_W \\ j &= 1, 2, \cdots, N_B . \end{aligned}$$

where L_{ij} is the length of wake element (i,j):

$$L_{ij} = \left[(x_{i+1,j} - x_{ij})^2 + (y_{i+1,j} - y_{ij})^2 + (z_{i+1,j} - z_{ij})^2 \right]^{1/2} \tag{7}$$

The value for $a_{1_j}(\psi)$, $j = 1, 2, \ldots, N_B$, are assigned as inputs.

<u>Effect of Rotor and Wake</u>

The velocity components induced by the blade and wake vortex elements may be represented by the following relations. Define $q_{x_{ij}}$, $q_{y_{ij}}$ and $q_{z_{ij}}$ by

$$\begin{aligned} q_{x_{ij}} &= \nu_x G \\ q_{y_{ij}} &= \nu_y G \\ q_{z_{ij}} &= \nu_z G \end{aligned} \tag{8}$$

where

$$\nu_x = (y - y_{ij})(z_{ij} - z_{i+1,j}) - (z - z_{ij})(y_{ij} - y_{i+1,j})$$

$$\nu_y = (z - z_{ij})(x_{ij} - x_{i+1,j}) - (x - x_{ij})(z_{ij} - z_{i+1,j})$$

$$\nu_z = (x - x_{ij})(y_{ij} - y_{i+1,j}) - (y - y_{ij})(x_{ij} - x_{i+1,j})$$

$$G = \Gamma_{ij} \left\{ \frac{r_{ij} + r_{i+1,j}}{r_{ij} r_{i+1,j} \left[(r_{ij} + r_{i+1,j})^2 - L_{ij}^2 \right]} \right\}$$

$$r_{ij} = \left[(x - x_{ij})^2 + (y - y_{ij})^2 + (z - z_{ij})^2 \right]^{1/2}$$

Then, if point (x,y,z) does not lie on a vortex (i.e., is not a wake reference point), wake-induced and blade-induced velocity components are given by

$$\begin{aligned} V_{x_w}(x,y,z) &= \sum_{i=0}^{N_W} \sum_{j=1}^{N_B} q_{x_{ij}}(x,y,z) \\ V_{y_w}(x,y,z) &= \sum_{i=0}^{N_W} \sum_{j=1}^{N_B} q_{y_{ij}}(x,y,z) \\ V_{z_w}(x,y,z) &= \sum_{i=0}^{N_W} \sum_{j=1}^{N_B} q_{z_{ij}}(x,y,z) \end{aligned} \tag{9}$$

If the point in question is a wake reference point, say P_{rs}, then

$$V_{x_w}(x_{rs}, y_{rs}, z_{rs}) = \sum_{i=0}^{N_W} \sum_{\substack{j=1 \\ j \neq s}}^{N_B} q_{x_{ij}}(x_{rs}, y_{rs}, z_{rs})$$

$$+ \sum_{\substack{i=0 \\ i \neq r-1, r}}^{N_W} q_{x_{is}}(x_{rs}, y_{rs}, z_{rs}) + q_{s_x}(x_{rs}, y_{rs}, z_{rs}) \tag{10}$$

and similarly for V_{y_w} and V_{z_w}. The functions q_{s_x}, q_{s_y} and q_{s_z} account for self-induced effects. If $r>1$, these functions are given by

$$\begin{aligned} q_{s_x}(x_{rs}, y_{rs}, z_{rs}) &= m_x \mathcal{F} \\ q_{s_y}(x_{rs}, y_{rs}, z_{rs}) &= m_y \mathcal{F} \\ q_{s_z}(x_{rs}, y_{rs}, z_{rs}) &= m_z \mathcal{F} \end{aligned} \tag{11}$$

where

$$m_x = (y_{r-1,s} - y_{rs})(z_{rs} - z_{r+1,s}) - (y_{rs} - y_{r+1,s})(z_{r-1,s} - z_{rs})$$

$$m_y = (z_{r-1,s} - z_{rs})(x_{rs} - x_{r+1,s}) - (z_{rs} - z_{r+1,s})(x_{r-1,s} - x_{rs})$$

$$m_z = (x_{r-1,s} - x_{rs})(y_{rs} - y_{r+1,s}) - (x_{rs} - x_{r+1,s})(y_{r-1,s} - y_{rs})$$

$$\mathcal{F} = \frac{1}{4\mathcal{R}\sqrt{m_x^2 + m_y^2 + m_z^2}} \left\{ \Gamma_{r-1,s}\left[\ln\left(\frac{8f}{a_{r-1,s}}\right) + \frac{1}{4}\right] + \Gamma_{rs}\left[\ln\left(\frac{8g}{a_{rs}}\right) + \frac{1}{4}\right]\right\}$$

$$\mathcal{R} = \frac{L_{r-1,s}\, L_{rs}\, \delta_{rs}}{\left[4L_{r-1,s}^2 L_{rs}^2 - \left(L_{r-1,s}^2 + L_{rs}^2 - \delta_{rs}^2\right)^2\right]^{1/2}}$$

L_{rs} is as defined previously,

$$\delta_{rs} = \left[\left(x_{r-1,s} - x_{r+1,s}\right)^2 + \left(y_{r-1,s} - y_{r+1,s}\right)^2 + \left(z_{r-1,s} - z_{r+1,s}\right)^2\right]^{1/2}$$

$$f = \begin{cases} \frac{1}{L_{r-1,s}}\left[2\mathcal{R} - \sqrt{4\mathcal{R}^2 - L_{r-1,s}^2}\right], & L_{r-1,s}^2 \le d_{rs}^2 + L_{rs}^2 \\ \frac{1}{L_{r-1,s}}\left[2\mathcal{R} + \sqrt{4\mathcal{R}^2 - L_{r-1,s}^2}\right], & L_{r-1,s}^2 > d_{rs}^2 + L_{rs}^2 \end{cases}$$

$$g = \begin{cases} \frac{1}{L_{rs}}\left[2\mathcal{R} - \sqrt{4\mathcal{R}^2 - L_{rs}^2}\right], & L_{rs}^2 \le d_{rs}^2 + L_{r-1,s}^2 \\ \frac{1}{L_{rs}}\left[2\mathcal{R} + \sqrt{4\mathcal{R}^2 - L_{rs}^2}\right], & L_{rs}^2 > d_{rs}^2 + L_{r-1,s}^2 \end{cases}$$

If $r = 1$, self-induced effects must be modified to properly account for the proximity of the blade vortex. In this case,

$$q_{s_x}(x_{1s}, y_{1s}, z_{1s}) = q_{s_x}(x_{2s}, y_{2s}, z_{2s})\Big|_{\Gamma_{2s} \equiv 0}$$

$$q_{s_y}(x_{1s}, y_{1s}, z_{1s}) = q_{s_y}(x_{2s}, y_{2s}, z_{2s})\Big|_{\Gamma_{2s} \equiv 0}$$

$$\begin{aligned} q_{s_z}(x_{1s}, y_{1s}, z_{1s}) = {} & q_{s_z}(x_{2s}, y_{2s}, z_{2s})\Big|_{\Gamma_{2s} \equiv 0} \\ & - \frac{\Gamma_{Bs}}{\Delta\psi}\left\{\frac{R}{b}\Delta\psi - \sqrt{\frac{R}{b}\Delta\psi\left(\frac{R}{b}\Delta\psi + 2\right)}\right. \\ & \left. + \ln\left[1 + \frac{R}{b}\Delta\psi + \sqrt{\frac{R}{b}\Delta\psi\left(\frac{R}{b}\Delta\psi + 2\right)}\right]\right\} \end{aligned} \tag{12}$$

where Γ_{B_s} is the strength of blade element s and $\frac{R}{b}$ is the ratio of rotor radius to blade semichord. By the notation

$$q_{s_x}(x_{2s}, y_{2s}, z_{2s})\Big|_{\Gamma_{2s} \equiv 0}$$

is meant the value for $q_{s_x}(x_{2s}, y_{2s}, z_{2s})$ which is obtained if zero is substituted for the value of Γ_{2s}.

Effect of Fuselage

The following quantities, which are defined in The Formulations For The Supplementary Fuselage Program, are supplied as inputs from the supplemental fuselage program:

$$\sigma_{x_m},\ \sigma_{z_m};$$

$$\xi_{k_m},\ \eta_{k_m},\ d_{k_m};\ \bar{x}_m,\ \bar{y}_m,\ \bar{z}_m;$$

$$\lambda_{\eta_m},\ \mu_{\eta_m},\ \nu_{\eta_m};\ \lambda_{\zeta_m},\ \mu_{\zeta_m},\ \nu_{\zeta_m};$$

for $m = 1, 2, \cdots, N_f$ and $k = 1, 2, 3, 4.$

The fuselage contributions to the fluid velocity at a point (x, y, z) are given by

$$V_{x_f}(x, y, z) = \sum_{m=1}^{N_f} \left[\sigma_{x_m} V_{x_\infty} + \sigma_{z_m} V_{z_\infty}\right]\left[V_{x_m} + \bar{V}_{x_m}\right]$$

$$V_{y_f}(x, y, z) = \sum_{m=1}^{N_f} \left[\sigma_{x_m} V_{x_\infty} + \sigma_{z_m} V_{z_\infty}\right]\left[V_{y_m} - \bar{V}_{y_m}\right] \tag{13}$$

$$V_{z_f}(x, y, z) = \sum_{m=1}^{N_f} \left[\sigma_{x_m} V_{x_\infty} + \sigma_{z_m} V_{z_\infty}\right]\left[V_{z_m} + \bar{V}_{z_m}\right]$$

where

$$V_{x_\infty} = \frac{\mu}{\lambda} \cos \alpha_T$$

$$V_{z_\infty} = -\left(\frac{\mu}{\lambda} \sin \alpha_T + \sqrt{\frac{N_B}{2\lambda}}\right) K_f$$

and K_f is a correction factor, supplied as an input parameter, whose evaluation is discussed in Procedure For Implementation Of The Programs.

The quantities V_{x_m}, V_{y_m} and V_{z_m} are computed in the following manner. Using matrix notation,

$$\begin{bmatrix} V_{x_m} \\ V_{y_m} \\ V_{z_m} \end{bmatrix} = \begin{bmatrix} \lambda_{\xi_m} & \lambda_{\eta_m} & \lambda_{\zeta_m} \\ \mu_{\xi_m} & \mu_{\eta_m} & \mu_{\zeta_m} \\ \nu_{\xi_m} & \nu_{\eta_m} & \nu_{\zeta_m} \end{bmatrix} \begin{bmatrix} V_{\xi_m} \\ V_{\eta_m} \\ V_{\zeta_m} \end{bmatrix} \tag{14}$$

where $\lambda_{\xi_m}, \mu_{\xi_m}$ and ν_{ξ_m} are given in terms of input quantities:

$$\lambda_{\xi_m} = \mu_{\eta_m} \nu_{\zeta_m} - \mu_{\zeta_m} \nu_{\eta_m}$$

$$\mu_{\xi_m} = \nu_{\eta_m} \lambda_{\zeta_m} - \nu_{\zeta_m} \lambda_{\eta_m}$$

$$\nu_{\xi_m} = \lambda_{\eta_m} \mu_{\zeta_m} - \lambda_{\zeta_m} \mu_{\eta_m}$$

The quantities V_{ξ_m}, V_{η_m} and V_{ζ_m} are obtained in the following manner. First, d_{5m}^2 and d_{6m}^2 are computed:

$$d_{5m}^2 = \left(\xi_{3m} - \xi_{1m}\right)^2 + \left(\eta_{3m} - \eta_{1m}\right)^2$$
$$d_{6m}^2 = \left(\xi_{4m} - \xi_{2m}\right)^2 + \left(\eta_{4m} - \eta_{2m}\right)^2$$

and d_{7m}^2 is set equal to the larger of d_{5m}^2 or d_{6m}^2. Then ξ_m, η_m and ζ_m are obtained from

$$\begin{bmatrix} \xi_m \\ \eta_m \\ \zeta_m \end{bmatrix} = \begin{bmatrix} \lambda_{\xi_m} & \mu_{\xi_m} & \nu_{\xi_m} \\ \lambda_{\eta_m} & \mu_{\eta_m} & \nu_{\eta_m} \\ \lambda_{\zeta_m} & \mu_{\zeta_m} & \mu_{\zeta_m} \end{bmatrix} \begin{bmatrix} x - \bar{x}_m \\ y - \bar{y}_m \\ z - \bar{z}_m \end{bmatrix} \tag{15}$$

. l $r_{o_m}^2$ is computed from

$$r_{o_m}^2 = \xi_m^2 + \eta_m^2 + \zeta_m^2$$

Also, t_m^2 is obtained according to

$$t_m^2 = \frac{r_{o_m}^2}{d_{7m}^2} \tag{16}$$

If $t_m^2 > 6$, an approximate method is used to compute V_{ξ_m}, V_{η_m} and V_{ζ_m}. If $t_m^2 \leq 6$ the exact method is used (the accuracy of the approximate method is discussed in Reference 8).

<u>Approximate Method $(t_m^2 > 6)$</u>

$$V_{\xi_m} = \frac{S_m \xi_m}{r_{o_m}^3}$$

$$V_{\eta_m} = \frac{S_m \eta_m}{r_{o_m}^3}$$

$$V_{\zeta_m} = \frac{S_m \zeta_m}{r_{o_m}^3} \qquad (17)$$

where
$$S_m = \frac{1}{2}\left(\xi_{3m} - \xi_{1m}\right)\left(\eta_{2m} - \eta_{4m}\right)$$

Exact Method $(t_m^2 \leq 6)$

The following additional quantities are computed if the exact method is used (note: if a vertex subscript $k = 5$ is called for in any of the following equations this is understood to mean that $k = 1$ is to be used):

$$r_{km} = \left\{\left(\xi_m - \xi_{km}\right)^2 + \left(\eta_m - \eta_{km}\right)^2 + \zeta_m^2\right\}^{1/2}$$

$$e_{km} = \zeta_m^2 + \left(\xi_m - \xi_{km}\right)^2$$

$$h_{km} = \left(\eta_m - \eta_{km}\right)\left(\xi_m - \xi_{km}\right)$$

$$m_{km} = \frac{\eta_{k+1,m} - \eta_{km}}{\xi_{k+1,m} - \xi_{km}}$$

all for $k = 1, 2, 3, 4.$ Then

$$V_{\xi_m} = \sum_{k=1}^{4} \frac{\left(\eta_{k+1,m} - \eta_{km}\right)}{d_{km}} \ln\left[\frac{r_{km} + r_{k+1,m} - d_{km}}{r_{km} + r_{k+1,m} + d_{km}}\right]$$

$$V_{\eta_m} = \sum_{k=1}^{4} \frac{\left(\xi_{km} - \xi_{k+1,m}\right)}{d_{km}} \ln\left[\frac{r_{km} + r_{k+1,m} - d_{km}}{r_{km} + r_{k+1,m} + d_{km}}\right] \qquad (18)$$

$$V_{\zeta_m} = \sum_{k=1}^{4}\left\{\tan^{-1}\left[\frac{m_{km}\, e_{km} - h_{km}}{\zeta_m\, r_{km}}\right] - \tan^{-1}\left[\frac{m_{km}\, e_{k+1,m} - h_{k+1,m}}{\zeta_m\, r_{k+1,m}}\right]\right\}$$

where the arctangent is understood to lie between $-\frac{\pi}{2}$ and $\frac{\pi}{2}$.

The computation of $\overline{V}_{x_m}, \overline{V}_{y_m}$ and $\overline{V}_{z_m}$ is identical to that of V_{x_m}, V_{y_m} and V_{z_m}, respectively, except that instead of evaluating the various functions at the point (x,y,z), the point $(x,-y,z)$ is used. That is,

$$\overline{V}_{x_m}(x,y,z) = V_{x_m}(x,-y,z) \tag{19}$$

$$\overline{V}_{y_m}(x,y,z) = V_{y_m}(x,-y,z)$$

$$\overline{V}_{z_m}(x,y,z) = V_{z_m}(x,-y,z)$$

4. FORMULATIONS FOR THE SUPPLEMENTARY FUSELAGE PROGRAM

PRELIMINARY REMARKS

The formulations given below generally correspond to those reported in Reference 8, but adapted to the problem treated here. Referring now to the coordinate system of the section on Coordinate Identifications And Nomenclature above, it is assumed that the fuselage is symmetric with respect to the $x-z$ plane and that the free stream is parallel to that plane.

As a first step, that half of the fuselage for which y is positive is approximated by a mesh of quadrilateral elements. Those portions of the surface having large curvature must, of course, be divided into smaller elements than are adequate elsewhere. The elements are numbered sequentially, beginning with some convenient element, say at the nose.

Consider the m^{th} quadrilateral element ($m = 1, 2, \cdots, N_f$); its four vertices are numbered clockwise when viewing the element from the exterior of the fuselage, the selection of vertex 1 being arbitrary. The coordinates of these vertices, denoted $(x_{k_m}, y_{k_m}, z_{k_m})$ for $K = 1, 2, 3, 4$, are supplied as inputs to the program.

EQUATIONS FOR COMPUTATION

The major portion of the program is directed to obtaining two sets of linear algebraic equations having the normalized source strengths as unknowns. These two sets of equations may be written in the form

$$\left.\begin{aligned} \sum_{n=1}^{N_f} B_{mn}\,\sigma_{x_n} &= -\lambda_{\zeta_m} , \\ \sum_{n=1}^{N_f} B_{mn}\,\sigma_{z_n} &= -\nu_{\zeta_m} , \end{aligned}\right\} \quad m = 1, 2, \cdots, N_f . \tag{20}$$

The program then solves these equations by a standard iterative technique (convergence is rapid because the matrix of the coefficients B_{mn} is very nearly diagonal) to obtain the σ_{x_m}'s and σ_{z_m}'s.

The coefficients and inhomogeneous terms of Equations (20) are computed as follows. First, let

$$B_{mn} = A_{mn} + \bar{A}_{mn} \tag{21}$$

A_{mn} and $\bar{A}_{mn}$ relate directly to the velocities induced by element n and its image, respectively, on element m.

Computation of A_{mn}

First, the quantities

$$\alpha_{N_n} = (y_{4n} - y_{2n})(z_{3n} - z_{1n}) - (z_{4n} - z_{2n})(y_{3n} - y_{1n})$$

$$\beta_{N_n} = (z_{4n} - z_{2n})(x_{3n} - x_{1n}) - (x_{4n} - x_{2n})(z_{3n} - z_{1n})$$

$$\gamma_{N_n} = (x_{4n} - x_{2n})(y_{3n} - y_{1n}) - (y_{4n} - y_{2n})(x_{3n} - x_{1n}) \tag{22}$$

$$\bar{x}_n = \frac{1}{4}\sum_{k=1}^{4} x_{kn}\ , \quad \bar{y}_n = \frac{1}{4}\sum_{k=1}^{4} y_{kn}\ , \quad \bar{z}_{kn} = \frac{1}{4}\sum_{k=1}^{4} z_{kn}\ ;$$

are computed. These quantities are then used to compute

$$x''_{kn} = \frac{1}{(\alpha_{N_n}^2 + \beta_{N_n}^2 + \gamma_{N_n}^2)}\left\{(\beta_{N_n}^2 + \gamma_{N_n}^2)(x_{kn} - \bar{x}_n) - \alpha_{N_n}\beta_{N_n}(y_{kn} - \bar{y}_n) - \alpha_{N_n}\gamma_{N_n}(z_{kn} - \bar{z}_n)\right\}$$

$$y''_{kn} = \frac{1}{(\alpha_{N_n}^2 + \beta_{N_n}^2 + \gamma_{N_n}^2)}\left\{(\alpha_{N_n}^2 + \gamma_{N_n}^2)(y_{kn} - \bar{y}_n) - \beta_{N_n}\alpha_{N_n}(x_{kn} - \bar{x}_n) - \beta_{N_n}\gamma_{N_n}(z_{kn} - \bar{z}_n)\right\} \tag{23}$$

$$z''_{kn} = \frac{1}{(\alpha_{N_n}^2 + \beta_{N_n}^2 + \gamma_{N_n}^2)}\left\{(\alpha_{N_n}^2 + \beta_{N_n}^2)(z_{kn} - \bar{z}_n) - \gamma_{N_n}\alpha_{N_n}(x_{kn} - \bar{x}_n) - \gamma_{N_n}\beta_{N_n}(y_{kn} - \bar{y}_n)\right\}$$

for k = 1, 2, 3, and 4. These transformed coordinates are then utilized to compute the direction cosines $\lambda_{\xi_n}, \mu_{\xi_n}, \nu_{\xi_n}$:

$$\begin{bmatrix} \lambda_{\xi_n} \\ \mu_{\xi_n} \\ \nu_{\xi_n} \end{bmatrix} = \left[\left(x''_{3n} - x''_{1n} \right)^2 + \left(y''_{3n} - y''_{1n} \right)^2 + \left(z''_{3n} - z''_{1n} \right)^2 \right]^{-1/2} \begin{bmatrix} x''_{3n} - x''_{1n} \\ y''_{3n} - y''_{1n} \\ z''_{3n} - z''_{1n} \end{bmatrix} \tag{24}$$

Then $\lambda_{\zeta_n}, \mu_{\zeta_n}$ and ν_{ζ_n} are computed according to

$$\begin{bmatrix} \lambda_{\zeta_n} \\ \mu_{\zeta_n} \\ \nu_{\zeta_n} \end{bmatrix} = \left[\alpha_{N_n}^2 + \beta_{N_n}^2 + \gamma_{N_n}^2 \right]^{-1/2} \begin{bmatrix} \alpha_{N_n} \\ \beta_{N_n} \\ \gamma_{N_n} \end{bmatrix} \tag{25}$$

and the direction cosines obtained from Equations (24) and (25) are used in the computation of $\lambda_{\eta_n}, \mu_{\eta_n}$ and ν_{η_n} :

$$\begin{aligned} \lambda_{\eta_n} &= \mu_{\zeta_n} \nu_{\xi_n} - \mu_{\xi_n} \nu_{\zeta_n} \\ \mu_{\eta_n} &= \nu_{\zeta_n} \lambda_{\xi_n} - \nu_{\xi_n} \lambda_{\zeta_n} \\ \nu_{\eta_n} &= \lambda_{\zeta_n} \mu_{\xi_n} - \lambda_{\xi_n} \mu_{\zeta_n} \end{aligned} \tag{26}$$

Then, the following transformed coordinates are computed:

$$\begin{bmatrix} \xi_{mn} \\ \eta_{mn} \\ \zeta_{mn} \end{bmatrix} = \begin{bmatrix} \lambda_{\xi_n} & \mu_{\xi_n} & \nu_{\xi_n} \\ \lambda_{\eta_n} & \mu_{\eta_n} & \nu_{\eta_n} \\ \lambda_{\zeta_n} & \mu_{\zeta_n} & \nu_{\zeta_n} \end{bmatrix} \begin{bmatrix} \bar{x}_m - \bar{x}_n \\ \bar{y}_m - \bar{y}_n \\ \bar{z}_m - \bar{z}_n \end{bmatrix} \tag{27a}$$

$$\begin{bmatrix} \xi_{kn} \\ \eta_{kn} \end{bmatrix} = \begin{bmatrix} \lambda_{\xi_n} & \mu_{\xi_n} & \nu_{\xi_n} \\ \lambda_{\eta_n} & \mu_{\eta_n} & \nu_{\eta_n} \end{bmatrix} \begin{bmatrix} x''_{kn} \\ y''_{kn} \\ z''_{kn} \end{bmatrix} \tag{27b}$$

Next, the quantities

$$\begin{aligned} d_{5n}^2 &= \left(\xi_{3n} - \xi_{1n} \right)^2 + \left(\eta_{3n} - \eta_{1n} \right)^2 \\ d_{6n}^2 &= \left(\xi_{4n} - \xi_{2n} \right)^2 + \left(\eta_{4n} - \eta_{2n} \right)^2 \end{aligned} \tag{28}$$

are obtained, and $d_{7_n}^2$ is defined to be the larger of $d_{5_n}^2$ or $d_{6_n}^2$. Then

$$r_{o_{mn}}^2 = \xi_{mn}^2 + \eta_{mn}^2 + \zeta_{mn}^2 \tag{29}$$

and the quantity

$$t_{mn}^2 = \frac{r_{o_{mn}}^2}{d_{7_n}^2} \tag{30}$$

are computed. If $t_{mn}^2 > 6$, an approximate method is used. If $t_{mn}^2 \leq 6$, the exact formulation is applied. In either case, the quantities $V_{\xi_{mn}}$, $V_{\eta_{mn}}$ and $V_{\zeta_{mn}}$ are computed, which in turn are used to evaluate

$$\begin{bmatrix} V_{x_{mn}} \\ V_{y_{mn}} \\ V_{z_{mn}} \end{bmatrix} = \begin{bmatrix} \lambda_{\xi_n} & \lambda_{\eta_n} & \lambda_{\zeta_n} \\ \mu_{\xi_n} & \mu_{\eta_n} & \mu_{\zeta_n} \\ \nu_{\xi_n} & \nu_{\eta_n} & \nu_{\zeta_n} \end{bmatrix} \begin{bmatrix} V_{\xi_{mn}} \\ V_{\eta_{mn}} \\ V_{\zeta_{mn}} \end{bmatrix} \tag{31}$$

whereupon

$$A_{mn} = \lambda_{\zeta_m} V_{x_{mn}} + \mu_{\zeta_m} V_{y_{mn}} + \nu_{\zeta_m} V_{z_{mn}} \tag{32}$$

Computation of $V_{\xi_{mn}}, V_{\eta_{mn}}, V_{\zeta_{mn}}$ by Approximate Method ($t_{mn}^2 > 6$)

In this case,

$$\begin{bmatrix} V_{\xi_{mn}} \\ V_{\eta_{mn}} \\ V_{\zeta_{mn}} \end{bmatrix} = \frac{S_n}{r_{o_{mn}}^3} \begin{bmatrix} \xi_{mn} \\ \eta_{mn} \\ \zeta_{mn} \end{bmatrix} \tag{33}$$

where

$$S_n = \frac{1}{2} \left[\xi_{3_n} - \xi_{1_n} \right] \left[\eta_{2_n} - \eta_{4_n} \right]$$

Computation of $V_{\xi_{mn}}, V_{\eta_{mn}}, V_{\zeta_{mn}}$ by Exact Method ($t_{mn}^2 \leq 6$)

The following additional quantities are first computed (note: in the following equations, if a vertex subscript $k = 5$ is called for, this is understood to mean that $k = 1$ is to be used):

$$d_{kn} = \left[\left(\xi_{k+1,n} - \xi_{kn}\right)^2 + \left(\eta_{k+1,n} - \eta_{kn}\right)^2\right]^{1/2}$$

$$r_{kmn} = \left[\left(\xi_{mn} - \xi_{kn}\right)^2 + \left(\eta_{mn} - \eta_{kn}\right)^2 + \zeta_{mn}^2\right]^{1/2}$$

$$e_{kmn} = \zeta_{mn}^2 + \left(\xi_{mn} - \xi_{kn}\right)^2$$

$$h_{kmn} = \left(\eta_{mn} - \eta_{kn}\right)\left(\xi_{mn} - \xi_{kn}\right)$$

$$m_{kn} = \frac{\eta_{k+1,n} - \eta_{kn}}{\xi_{k+1,n} - \xi_{kn}}$$

all for $k = 1, 2, 3,$ and 4.
Then

$$V_{\xi_{mn}} = \sum_{k=1}^{4} \frac{(\eta_{k+1,n} - \eta_{kn})}{d_{kn}} \ln\left[\frac{r_{kmn} + r_{k+1,mn} - d_{kn}}{r_{kmn} + r_{k+1,mn} + d_{kn}}\right]$$

$$V_{\eta_{mn}} = \sum_{k=1}^{4} \frac{(\xi_{kn} - \xi_{k+1,n})}{d_{kn}} \ln\left[\frac{r_{kmn} + r_{k+1,mn} - d_{kn}}{r_{kmn} + r_{k+1,mn} + d_{kn}}\right] \tag{34}$$

$$V_{\zeta_{mn}} = \sum_{k=1}^{4} \left\{\tan^{-1}\left[\frac{m_{kn}\, e_{kmn} - h_{kmn}}{\zeta_{mn}\, r_{kmn}}\right] - \tan^{-1}\left[\frac{m_{kn}\, e_{k+1,mn} - h_{k+1,mn}}{\zeta_{mn}\, r_{k+1,mn}}\right]\right\}$$

where the arctangent is defined for the interval $-\frac{\pi}{2}$ to $\frac{\pi}{2}$.

Computation of $\bar{A}_{mn}$

The computation of $\bar{A}_{mn}$ is carried out in the same manner as that of A_{mn}, with two exceptions. First, the $\bar{y}$ coordinate of element m is replaced by its negative; specifically, $(\bar{x}_m, \bar{y}_m, \bar{z}_m)$ are replaced by $(\bar{x}_m, -\bar{y}_m, \bar{z}_m)$ in the computation of ξ_{mn}, η_{mn} and ζ_{mn}. Second, the formula for A_{mn} is altered slightly so that

$$\bar{A}_{mn} = \lambda_{\zeta_m} \bar{V}_{x_{mn}} - \mu_{\zeta_m} \bar{V}_{y_{mn}} + \nu_{\zeta_m} \bar{V}_{z_{mn}} \qquad (35)$$

where the bars over $V_{x_{mn}}$ etc., indicate that they were obtained using $-\bar{y}_m$ in place of $\bar{y}_m$.

It should be noted that certain indeterminacies are encountered in the formulas for A_{mn} (but not $\bar{A}_{mn}$) when $m = n$. The computation of A_{mn} is, therefore, omitted, and the proper limiting value for that quantity of 2π is specified.

5. PROCEDURES FOR IMPLEMENTATION OF THE PROGRAMS

THE MAIN PROGRAM

Assignment of Input Parameters

There are a number of input parameters, certain of which relate directly to aircraft flight conditions, and others which must be chosen on the basis of past experience and best judgement. Each of the input parameters is discussed individually below. A sample collection of these parameters is then given for a representative aircraft and flight condition.

1. Advance Ratio μ

Given the aircraft forward speed V_f in feet per second, rotor radius R in feet and rotor angular speed Ω in radians per second, μ is calculated according to

$$\mu = \frac{V_f}{\Omega R} \tag{36}$$

2. Number of Blades N_B

The program has the facility to handle rotors with up to four blades.

3. Loading Parameter λ

This parameter is given by

$$\lambda = \frac{4W}{\pi^2 N_B \rho \Omega^2 R^4} \tag{37}$$

where Ω, R and N_B are as defined in 1 and 2, ρ is the air density in slugs per cubic foot, and W is the total weight of the aircraft, in pounds.

4. Tip-Path-Plane Angle α_T, in Degrees

In the absence of measured data, the value for this angle may be estimated by the formula

$$\alpha_T = \left(\frac{360}{\pi^2 N_B}\right)\frac{C_{D_f}\mu^2}{\lambda}, \text{ degrees} \tag{38}$$

where C_{D_f} is the drag coefficient of the fuselage, defined by

$$C_{D_f} = \frac{D_f}{\frac{1}{2}\rho V_f^2 \pi R^2}$$

where D_f is fuselage drag.

5. Number of Azimuth Stations per Revolution, N_A.

Since running time increases rapidly with increasing N_A (approximately as N_A^3), a careful choice for this number must be made. It has been found that for a two-bladed rotor sufficient accuracy may be obtained with $N_A = 12$. It is difficult to define time variations of fluid velocities if N_A is less than this number (for $N_B = 2$), and running time becomes excessive if it is made larger.

6. Number of Revolutions of Wake per Blade, N_R.

The total number of wake elements included is proportional to N_R, so running time is also sensitive to this number. Generally, the higher the advance ratio, the smaller the value of N_R needed, provided interest in the flow is not directed to the far wake. For example, $N_R = 2$ is sufficient for $\mu = .25$ and $N_R = 4$ suffices for $\mu = .15$, to satisfactorily reproduce the flow directly beneath the rotor plane.

7. The Strength of Blade Element 1 as a Function of Azimuth

The normalized strength of blade element 1 at each azimuth station must be specified. In the absence of measured data, the formula

$$\Gamma_{B_1}(\psi) = 1 - 2\mu \sin\psi \tag{39}$$

provides a suitable appı ximation.

8. The Core Size of Each Wake Element, a_{ij}, at the Start of the Program

Each wake element (i,j) for $i = 1, 2, \ldots, N_R N_A$ and $j = 1, 2, \ldots, N_B$ must be assigned a core size in order to start the program. It has been found, by estimating the core sizes of wake vortices for numerous flight conditions, that

$$a_{ij}(\psi_{init}) \equiv .05 \qquad \begin{matrix} i = 1, 2, \cdots, N_R N_A \\ j = 1, 2, \cdots, N_B \end{matrix} \tag{40}$$

can be utilized for any normal operating condition of the rotor. The variations in core size from this value with changes in advance ratio and loading were found to be negligible in their effect on the flow.

9. The Core Size of the Wake Element Attached to Blade 1, a_{11}, as a Function of Azimuth

For the same reasons as noted in item (8) above, it is sufficient to let

$$a_{11}(\psi) = .05 \tag{41}$$

10. The Initial Value for the Azimuth Position of Blade 1, ψ_{init}, in Degrees, and the Number of Rotor Revolutions to be run, N_{RV}.

The value for ψ_{init} is, of course, arbitrary, and is generally made zero. If a case is being investigated for which a periodic flow may be obtained (which generally occurs for μ greater than about .08), it is desirable to make N_{RV} large enough to allow periodicity to be established. It has been found that, for a two-bladed rotor, a periodic flow is usually obtained after about N_R revolutions of the rotor. That is, if

$$N_{RV} \geq N_R \tag{42}$$

a periodic flow will be established.

11. Initial Wake Configuration

The option has been provided whereby the initial wake geometry; i. e., the coordinates of the wake reference points P_{ij}, $i = 1,2,\cdots,N_A N_R+1$, $j=1,2,\cdots,N_B$; may be specified as inputs or may be computed as part of the program. The computed configuration is a skewed helix with skew and pitch dependent on μ and λ. The option for specifying the geometry as input allows the program to be continued from a previously computed geometry. Thus, if additional information is desired after a run has been completed, the program may be restarted at the point where periodicity has been established rather than from a skew-helical configuration.

12. Coordinates of Points at Which Flow is to be Determined

The x, y and z coordinates of those points at which fluid velocity components are desired should be specified. The maximum number of points which can be handled is 300.

13. Correction Factor K_f

The value for the z-component of the free stream experienced by the fuselage, which is needed to assign the strengths of the fuselage source elements, may be estimated, using momentum considerations, to be

$$-\left(\frac{\mu}{\lambda}\sin\alpha_T + \sqrt{\frac{N_B}{2\lambda}}\right).$$

It has been found, though, that the average downwash experienced by the fuselage may, in some cases, differ considerably from this value. Therefore, a correction factor K_f has been applied to make the downwash used correspond to the correct value. The following procedure may be used to obtain the value of K_f.

First, the main program is run, with the fuselage representation omitted, until a periodic flow is established. The fluid velocity is computed during this run at several points (it has been found that 25 points are sufficient for a UH-1B fuselage) within the volume which the fuselage occupies. A simple average over one period of the value of V_z, as given on the output sheet,

is then computed for each point, and the spacial average of these is in turn computed. Denote this combined spacial and time average of V_z by $\overline{V}_z$. Then K_f is simply given by

$$K_f = \frac{-\overline{V}_z}{\left(\frac{\mu}{\lambda} \sin \alpha_T + \sqrt{\frac{N_B}{2\lambda}}\right)} \qquad (43)$$

14. Fuselage Parameters

All the parameters necessary for inclusion in the main program to represent the fuselage are obtained directly from the supplemental fuselage program. The latter program has been coded to punch the cards needed directly.

SAMPLE PROBLEM

For illustrative purposes, consider a UH-1B helicopter operating at a forward speed of 60 knots and a rotor speed of 300 rpm. The total weight of the aircraft is 5675 pounds, the drag coefficient of the fuselage, C_{D_f} , is .014, the rotor radius is 22 feet and the blade semichord is 10.5 inches. A programmer would then need, in addition to the appropriate outputs from the supplemental fuselage program, the information listed below.

Number of blades $N_B = 2$
Number of Revolutions of Wake $N_R = 4$
Number of Azimuth Stations $N_A = 12$

$\lambda = .00209$
$\mu = .1465$
$\alpha_T = 2.62$ degrees

V_{z_∞} correction factor $K_f = .2600$

$\frac{R}{b} = 25.1$

Number of fuselage elements $N_f = 96$

Ψ initial $= 0$
$N_{RV} = 4.5$

AZIMUTH ψ - deg	$\Gamma_{B_1}(\psi)$	$a_{11}(\psi)$
0	1.0	.05
30	.8535	
60	.746	
90	.707	
120	.746	
150	.8535	
180	1.0	
210	1.1465	
240	1.254	
270	1.293	
300	1.254	
330	1.1465	

Velocities are to be computed at:

x	y	z
-1	.3	-.4
-.5	.3	-.4
0	.3	-.4
.5	.3	-.4
1.0	.3	-.4

Selected pages from the output for this case are shown on the following pages. The first of these, listing the parameters, is self-explanatory. On the next pages, the station number, running from 1 to 49, refers to the first (i) subscript of the wake reference points, and, of course, the blade number is the second subscript (j). All velocity components printed out, i. e., those at the wake reference points and those at other points, are the quantities defined by Equations (3). Thus, the actual velocity components at the points in question, in dimensional form, would be obtained by multiplying the print-out variable by (λ) (ΩR).

THE SUPPLEMENTAL FUSELAGE PROGRAM

Operation of the supplemental fuselage program requires specification of the number N_f of fuselage elements to be considered and the coordinates of the four vertices of each of these elements. As noted previously, the size of these elements must be varied, depending on local curvature and the accuracy of the flow representation desired. Computing time for the main program increases rapidly with N_f, so as large an element size as possible, compatible with accuracy requirements, should be selected.

As an example, the inputs used for computing the source strengths needed to represent an idealized UH-1B fuselage are tabulated on the pages which follow. The element sizes chosen for this case appear to provide a reasonable compromise in meeting running time and accuracy requirements. Note that the vertices are numbered in the clockwise sense with the element viewed from outside the fuselage.

HELICOPTER WAKE VORTICITY PROGRAM

```
NUMBER OF BLADES                  =          2
NUMBER OF REVOLUTIONS OF WAKE     =          4
NUMBER OF AZIMUTH STATIONS        =         12
NUMBER OF FUSELAGE POINTS         =         96
PSI (INITIAL)             =       0.    DEGREES
PSI (FINAL)               =    1620.000 DEGREES
LAMBDA                    = 0.20900E-02
MU                        = 0.14650E 00
ALPHAT                    =       2.620 DEGREES
R/B                       =      25.100
VZ INFINITY FACTOR        =       0.260
```

PSI	STRENGTH OF BLADE 1	CORE SIZE AT BLADE 1
0.	0.10000E 01	0.50000E-01
30.000	0.85350E 00	0.50000E-01
60.000	0.74600E 00	0.50000E-01
90.000	0.70700E 00	0.50000E-01
120.000	0.74600E 00	0.50000E-01
150.000	0.85350E 00	0.50000E-01
180.000	0.10000E 01	0.50000E-01
210.000	0.11465E 01	0.50000E-01
240.000	0.12540E 01	0.50000E-01
270.000	0.12930E 01	0.50000E-01
300.000	0.12540E 01	0.50000E-01
330.000	0.11465E 01	0.50000E-01

HELICOPTER WAKE VORTICITY DISTRIBUTION

NO. OF BLADES = 2 NO. OF AZIMUTH STATIONS = 12 NO. OF REV. OF WAKE = 4

LAMBDA = 0.20900E-02 MU = 0.14650E 00 ALPHA T = 2.620 DEG. DELTA PSI = 30.000 DEG.

PSI = 0. DEGREES

BLADE NUMBER 1

STAT.	X	Y	Z	VX	VY	VZ	STRENGTH	CORE SIZE
1	0.10000E 01	0.	-0.	0.71722E 02	-0.10941E 00	-0.19340E 02	0.10732E 01	0.50000E-01
2	0.94265E 00	-0.50000E 00	-0.27444E-01	0.72138E 02	0.37358E 01	-0.16832E 02	0.12002E 01	0.50000E-01
3	0.65325E 00	-0.86603E 00	-0.54887E-01	0.73153E 02	0.81211E 01	-0.13201E 02	0.12735E 01	0.50000E-01
4	0.22988E 00	-0.10000E 01	-0.82331E-01	0.72902E 02	0.42028E 01	-0.57361E 01	0.12735E 01	0.50000E-01
5	-0.19349E 00	-0.86603E 00	-0.10977E 00	0.71771E 02	0.90857E 00	-0.56109E 01	0.12002E 01	0.50000E-01
6	-0.48289E 00	-0.50000E 00	-0.13722E 00	0.71168E 02	-0.13297E 01	-0.43986E 01	0.10732E 01	0.50000E-01
7	-0.54024E 00	-0.61584E-07	-0.16466E 00	0.64338E 02	-0.53488E 01	0.14918E 01	0.92675E 00	0.50000E-01
8	-0.32964E 00	0.50000E 00	-0.19210E 00	0.71289E 02	0.17683E 01	-0.75270E 01	0.79975E 00	0.50000E-01
9	0.11302E 00	0.86603E 00	-0.21955E 00	0.71216E 02	0.22094E 01	-0.65286E 01	0.72650E 00	0.50000E-01
10	0.68964E 00	0.10000E 01	-0.24699E 00	0.73601E 02	-0.12185E 01	-0.90768E 00	0.72650E 00	0.50000E-01
11	0.12663E 01	0.86603E 00	-0.27444E 00	0.72707E 02	-0.65163E 01	-0.84024E 01	0.79975E 00	0.50000E-01
12	0.17089E 01	0.50000E 00	-0.30188E 00	0.72207E 02	-0.31396E 01	-0.12797E 02	0.92675E 00	0.50000E-01
13	0.19195E 01	0.12317E-06	-0.32932E 00	0.72216E 02	-0.15990E 00	-0.14634E 02	0.10732E 01	0.50000E-01
14	0.18622E 01	-0.50000E 00	-0.35677E 00	0.72673E 02	0.31446E 01	-0.15183E 02	0.12002E 01	0.50000E-01
15	0.15728E 01	-0.86603E 00	-0.38421E 00	0.73911E 02	0.69622E 01	-0.11576E 02	0.12735E 01	0.50000E-01
16	0.11494E 01	-0.10000E 01	-0.41165E 00	0.74620E 02	0.51544E 00	-0.39922E 01	0.12735E 01	0.50000E-01
17	0.72603E 00	-0.86603E 00	-0.43910E 00	0.73138E 02	-0.54737E 01	-0.11570E 02	0.12002E 01	0.50000E-01
18	0.43663E 00	-0.50000E 00	-0.46654E 00	0.70563E 02	-0.40509E 00	-0.13783E 02	0.10732E 01	0.50000E-01
19	0.37929E 00	-0.21455E-06	-0.49398E 00	0.64176E 02	0.11753E 01	-0.80013E 01	0.92675E 00	0.50000E-01
20	0.58989E 00	0.50000E 00	-0.52143E 00	0.70252E 02	0.17663E 01	-0.10967E 02	0.79975E 00	0.50000E-01
21	0.10325E 01	0.86603E 00	-0.54887E 00	0.72386E 02	0.57693E 01	-0.79977E 01	0.72650E 00	0.50000E-01
22	0.16092E 01	0.10000E 01	-0.57631E 00	0.74471E 02	-0.71195E-01	-0.25152E 00	0.72650E 00	0.50000E-01
23	0.21858E 01	0.86603E 00	-0.60376E 00	0.72867E 02	-0.61382E 01	-0.81025E 01	0.79975E 00	0.50000E-01
24	0.26284E 01	0.50000E 00	-0.63120E 00	0.71589E 02	-0.27302E 01	-0.12476E 02	0.92675E 00	0.50000E-01
25	0.28390E 01	0.24633E-06	-0.65864E 00	0.71179E 02	-0.68731E-01	-0.13807E 02	0.10732E 01	0.50000E-01
26	0.27817E 01	-0.50000E 00	-0.68609E 00	0.71984E 02	0.27064E 01	-0.14658E 02	0.12002E 01	0.50000E-01
27	0.24923E 01	-0.86603E 00	-0.71353E 00	0.73737E 02	0.64947E 01	-0.11363E 02	0.12735E 01	0.50000E-01
28	0.20689E 01	-0.10000E 01	-0.74098E 00	0.74801E 02	-0.29728E-01	-0.37656E 01	0.12735E 01	0.50000E-01
29	0.16456E 01	-0.86603E 00	-0.76842E 00	0.73904E 02	-0.65765E 01	-0.11438E 02	0.12002E 01	0.50000E-01
30	0.13562E 01	-0.50000E 00	-0.79586E 00	0.72434E 02	-0.27174E 01	-0.15020E 02	0.10732E 01	0.50000E-01
31	0.12988E 01	-0.27812E-06	-0.82331E 00	0.71815E 02	0.42995E 00	-0.14331E 02	0.92675E 00	0.50000E-01
32	0.15094E 01	0.50000E 00	-0.85075E 00	0.72089E 02	0.31290E 01	-0.12557E 02	0.79975E 00	0.50000E-01
33	0.19521E 01	0.86603E 00	-0.87819E 00	0.72951E 02	0.63195E 01	-0.81576E 01	0.72650E 00	0.50000E-01
34	0.25287E 01	0.10000E 01	-0.90564E 00	0.74242E 02	0.33011E 00	-0.54638E 00	0.72650E 00	0.50000E-01
35	0.31053E 01	0.86603E 00	-0.93308E 00	0.71579E 02	-0.47007E 01	-0.80242E 01	0.79975E 00	0.50000E-01
36	0.35480E 01	0.50000E 00	-0.96052E 00	0.70169E 02	-0.12675E 01	-0.94749E 01	0.92675E 00	0.50000E-01
37	0.37586E 01	0.42911E-06	-0.98797E 00	0.70045E 02	-0.19994E 00	-0.96375E 01	0.10732E 01	0.50000E-01
38	0.37012E 01	-0.50000E 00	-0.10154E 01	0.70261E 02	0.76774E 00	-0.10520E 02	0.12002E 01	0.50000E-01
39	0.34118E 01	-0.86603E 00	-0.10429E 01	0.71838E 02	0.37960E 01	-0.10566E 02	0.12735E 01	0.50000E-01
40	0.29885E 01	-0.10000E 01	-0.10703E 01	0.74195E 02	-0.95348E 00	-0.41586E 01	0.12735E 01	0.50000E-01
41	0.25651E 01	-0.86603E 00	-0.10977E 01	0.73790E 02	-0.70689E 01	-0.11655E 02	0.12002E 01	0.50000E-01
42	0.22757E 01	-0.50000E 00	-0.11252E 01	0.72658E 02	-0.31466E 01	-0.15282E 02	0.10732E 01	0.50000E-01
43	0.22183E 01	-0.34168E-06	-0.11526E 01	0.72161E 02	0.25802E 00	-0.15059E 02	0.92675E 00	0.50000E-01
44	0.24289E 01	0.50000E 00	-0.11801E 01	0.71884E 02	0.33524E 01	-0.13854E 02	0.79975E 00	0.50000E-01
45	0.28716E 01	0.86603E 00	-0.12075E 01	0.72053E 02	0.71450E 01	-0.98800E 01	0.72650E 00	0.50000E-01
46	0.34482E 01	0.10000E 01	-0.12350E 01	0.72533E 02	0.41173E 01	-0.23950E 01	0.72650E 00	0.50000E-01
47	0.40248E 01	0.86603E 00	-0.12624E 01	0.71477E 02	0.85513E 00	-0.27739E 01	0.79975E 00	0.50000E-01
48	0.44675E 01	0.50000E 00	-0.12898E 01	0.71013E 02	0.14579E 00	-0.33192E 01	0.92675E 00	0.50000E-01
49	0.46781E 01	0.49267E-06	-0.13173E 01	0.	0.	0.	0.	0.

HELICOPTER WAKE VORTICITY DISTRIBUTION

NO. OF BLADES = 2 NO. OF AZIMUTH STATIONS = 12 NO. OF REV. OF WAKE = 4
LAMBDA = 0.20900E-02 MU = 0.14650E 00 ALPHA T = 2.620 DEG. DELTA PSI = 30.000 DEG.

PSI = 0. DEGREES

BLADE NUMBER 2

STAT.	X	Y	Z	VX	VY	VZ	STRENGTH	CORE SIZE
1	-0.10000E 01	0.17791E-08	-0.	0.70102E 02	0.18386E 00	-0.69979E 01	0.92675E 00	0.50000E-01
2	-0.78940E 00	0.50000E 00	-0.27444E-01	0.70715E 02	0.46633E 00	-0.40884E 01	0.79975E 00	0.50000E-01
3	-0.34675E 00	0.86603E 00	-0.54887E-01	0.71767E 02	-0.60479E 00	-0.30441E 01	0.72650E 00	0.50000E-01
4	0.22988E 00	0.10000E 01	-0.82331E-01	0.72711E 02	-0.42618E 01	-0.23479E 01	0.72650E 00	0.50000E-01
5	0.80651E 00	0.86603E 00	-0.10977E 00	0.72010E 02	-0.72851E 01	-0.95936E 01	0.79975E 00	0.50000E-01
6	0.12492E 01	0.50000E 00	-0.13722E 00	0.71762E 02	-0.33110E 01	-0.13526E 02	0.92675E 00	0.50000E-01
7	0.14598E 01	0.59605E-07	-0.16466E 00	0.72047E 02	-0.65342E-01	-0.15116E 02	0.10732E 01	0.50000E-01
8	0.14024E 01	-0.50000E 00	-0.19210E 00	0.72568E 02	0.33602E 01	-0.15565E 02	0.12002E 01	0.50000E-01
9	0.11130E 01	-0.86603E 00	-0.21955E 00	0.73728E 02	0.72971E 01	-0.11956E 02	0.12735E 01	0.50000E-01
10	0.68764E 00	-0.10000E 01	-0.24699E 00	0.74195E 02	0.12361E 01	-0.44524E 01	0.12735E 01	0.50000E-01
11	0.26627E 00	-0.86603E 00	-0.27444E 00	0.72041E 02	-0.33801E 01	-0.10847E 02	0.12002E 01	0.50000E-01
12	-0.23128E-01	-0.50000E 00	-0.30188E 00	0.71842E 02	-0.57839E-01	-0.10877E 02	0.10732E 01	0.50000E-01
13	-0.80476E-01	-0.12119E-06	-0.32932E 00	0.82354E 02	-0.49099E 00	-0.15282E 02	0.92675E 00	0.50000E-01
14	0.13013E 00	0.50000E 00	-0.35677E 00	0.70980E 02	-0.16286E 00	-0.94837E 01	0.79975E 00	0.50000E-01
15	0.57278E 00	0.86603E 00	-0.38421E 00	0.71572E 02	0.45103E 01	-0.77773E 01	0.72650E 00	0.50000E-01
16	0.11494E 01	0.10000E 01	-0.41165E 00	0.74203E 02	-0.35519E 00	-0.39660E 00	0.72650E 00	0.50000E-01
17	0.17260E 01	0.86603E 00	-0.43910E 00	0.72935E 02	-0.62963E 01	-0.81231E 01	0.79975E 00	0.50000E-01
18	0.21687E 01	0.50000E 00	-0.46654E 00	0.72135E 02	-0.30325E 01	-0.12632E 02	0.92675E 00	0.50000E-01
19	0.23793E 01	0.24238E-06	-0.49398E 00	0.71948E 02	-0.15537E 00	-0.14408E 02	0.10732E 01	0.50000E-01
20	0.23219E 01	-0.50000E 00	-0.52143E 00	0.72513E 02	0.29854E 01	-0.14991E 02	0.12002E 01	0.50000E-01
21	0.20325E 01	-0.86603E 00	-0.54887E 00	0.73918E 02	0.67476E 01	-0.11430E 02	0.12735E 01	0.50000E-01
22	0.16092E 01	-0.10000E 01	-0.57631E 00	0.74785E 02	0.18926E 00	-0.38143E 01	0.12735E 01	0.50000E-01
23	0.11858E 01	-0.86603E 00	-0.60376E 00	0.73680E 02	-0.62387E 01	-0.11485E 02	0.12002E 01	0.50000E-01
24	0.89640E 00	-0.50000E 00	-0.63120E 00	0.71743E 02	-0.21026E 01	-0.14811E 02	0.10732E 01	0.50000E-01
25	0.83905E 00	-0.33376E-06	-0.65864E 00	0.70604E 02	0.74462E 00	-0.13530E 02	0.92675E 00	0.50000E-01
26	0.10497E 01	0.50000E 00	-0.68609E 00	0.71416E 02	0.28626E 01	-0.12214E 02	0.79975E 00	0.50000E-01
27	0.14723E 01	0.86603E 00	-0.71353E 00	0.72839E 02	0.61670E 01	-0.80305E 01	0.72650E 00	0.50000E-01
28	0.20689E 01	0.10000E 01	-0.74098E 00	0.74487E 02	0.82055E-01	-0.29840E 00	0.72650E 00	0.50000E-01
29	0.26456E 01	0.86603E 00	-0.76842E 00	0.72453E 02	-0.57806E 01	-0.81960E 01	0.79975E 00	0.50000E-01
30	0.30882E 01	0.50000E 00	-0.79586E 00	0.70636E 02	-0.20128E 01	-0.11526E 02	0.92675E 00	0.50000E-01
31	0.32988E 01	0.36554E-06	-0.82331E 00	0.70300E 02	-0.93169E-01	-0.12155E 02	0.10732E 01	0.50000E-01
32	0.32415E 01	-0.50000E 00	-0.85075E 00	0.70896E 02	0.19257E 01	-0.13502E 02	0.12002E 01	0.50000E-01
33	0.29521E 01	-0.86603E 00	-0.87819E 00	0.73192E 02	0.58928E 01	-0.11304E 02	0.12735E 01	0.50000E-01
34	0.25287E 01	-0.10000E 01	-0.90564E 00	0.74659E 02	-0.30003E 00	-0.38217E 01	0.12735E 01	0.50000E-01
35	0.21053E 01	-0.86603E 00	-0.93308E 00	0.73940E 02	-0.67932E 01	-0.11471E 02	0.12002E 01	0.50000E-01
36	0.18159E 01	-0.50000E 00	-0.96052E 00	0.72681E 02	-0.29689E 01	-0.15121E 02	0.10732E 01	0.50000E-01
37	0.17586E 01	-0.51653E-06	-0.98797E 00	0.72217E 02	0.31243E 00	-0.14594E 02	0.92675E 00	0.50000E-01
38	0.19692E 01	0.50000E 00	-0.10154E 01	0.72241E 02	0.32088E 01	-0.12842E 02	0.79975E 00	0.50000E-01
39	0.24118E 01	0.86603E 00	-0.10429E 01	0.72761E 02	0.65029E 01	-0.85704E 01	0.72650E 00	0.50000E-01
40	0.29885E 01	0.10000E 01	-0.10703E 01	0.73600E 02	0.10892E 01	-0.11054E 01	0.72650E 00	0.50000E-01
41	0.35651E 01	0.86603E 00	-0.10977E 01	0.70890E 02	-0.24139E 01	-0.65126E 01	0.79975E 00	0.50000E-01
42	0.40077E 01	0.50000E 00	-0.11252E 01	0.70301E 02	-0.64560E 00	-0.68711E 01	0.92675E 00	0.50000E-01
43	0.42183E 01	0.42911E-06	-0.11526E 01	0.70464E 02	-0.29490E 00	-0.63989E 01	0.10732E 01	0.50000E-01
44	0.41610E 01	-0.50000E 00	-0.11801E 01	0.70912E 02	-0.40049E 00	-0.58415E 01	0.12002E 01	0.50000E-01
45	0.38716E 01	-0.86603E 00	-0.12075E 01	0.71393E 02	-0.10542E 01	-0.57506E 01	0.12735E 01	0.50000E-01
46	0.34482E 01	-0.10000E 01	-0.12350E 01	0.72724E 02	-0.40178E 01	-0.55187E 01	0.12735E 01	0.50000E-01
47	0.30248E 01	-0.86603E 00	-0.12624E 01	0.73157E 02	-0.78470E 01	-0.12702E 02	0.12002E 01	0.50000E-01
48	0.27354E 01	-0.50000E 00	-0.12898E 01	0.72314E 02	-0.34735E 01	-0.15774E 02	0.10732E 01	0.50000E-01
49	0.26781E 01	-0.58010E-06	-0.13173E 01	0.	0.	0.	0.	0.

HELICOPTER WAKE VORTICITY DISTRIBUTION

NO. OF BLADES = 2 | NO. OF AZIMUTH STATIONS = 12 | NO. OF REV. OF WAKE = 4

LAMBDA = 0.20900E-02 | MU = 0.14650E 00 | ALPHA T = 2.620 DEG. | DELTA PSI = 30.000 DEG.

PSI = 0. DEGREES

VELOCITIES AT OTHER POINTS

X	Y	Z	VX	VY	VZ
-0.10000E 01	0.30000E 00	-0.40000E 00	0.67616E 02	0.94072E 00	-0.26322E 01
-0.50000E 00	0.30000E 00	-0.40000E 00	0.65756E 02	0.61400E 01	-0.57287E 01
0.	0.30000E 00	-0.40000E 00	0.64356E 02	0.11034E 01	-0.37500E 00
0.50000E 00	0.30000E 00	-0.40000E 00	0.77490E 02	-0.32539E 01	-0.10791E 02
0.10000E 01	0.30000E 00	-0.40000E 00	0.75744E 02	-0.39297E 00	-0.14795E 02

HELICOPTER WAKE VORTICITY DISTRIBUTION

NO. OF BLADES = 2 | NO. OF AZIMUTH STATIONS = 12 | NO. OF REV. OF WAKE = 4
LAMBDA = 0.20900E-02 | MU = 0.14650E 00 | ALPHA T = 2.620 DEG. | DELTA PSI = 30.000 DEG.

PSI = 30.000 DEGREES

BLADE NUMBER 1

STAT.	X	Y	Z	VX	VY	VZ	STRENGTH	CORE SIZE
1	0.86603E 00	0.50000E 00	0.	0.71749E 02	-0.34935E 01	-0.17381E 02	0.92675E 00	0.50000E-01
2	0.10785E 01	-0.11973E-03	-0.21165E-01	0.71727E 02	-0.51437E-01	-0.16223E 02	0.10732E 01	0.50218E-01
3	0.10216E 01	-0.49591E 00	-0.45863E-01	0.72094E 02	0.36191E 01	-0.16581E 02	0.12002E 01	0.50251E-01
4	0.73331E 00	-0.85714E 00	0.69333E-01	0.73059E 02	0.80395E 01	-0.13388E 02	0.12735E 01	0.49936E-01
5	0.30366E 00	-0.99540E 00	-0.88608E-01	0.72876E 02	0.42287E 01	-0.57440E 01	0.12735E 01	0.49994E-01
6	-0.11495E 00	-0.86503E 00	-0.11591E 00	0.71837E 02	0.93047E 00	-0.54277E 01	0.12002E 01	0.50085E-01
7	-0.40501E 00	-0.50146E 00	-0.14203E 00	0.72245E 02	-0.26341E 01	-0.32800E 01	0.10732E 01	0.50188E-01
8	-0.46983E 00	-0.58534E-02	-0.16303E 00	0.65080E 02	-0.17749E 01	0.26351E 01	0.92675E 00	0.49514E-01
9	-0.25162E 00	0.50194E 00	-0.20034E 00	0.71617E 02	0.16976E 01	-0.73209E 01	0.79975E 00	0.49992E-01
10	0.19095E 00	0.86844E 00	-0.2[illegible]569E 00	0.71132E 02	0.23835E 01	-0.62708E 01	0.72650E 00	0.49939E-01
11	0.77019E 00	0.99861E 00	-0.24799E 00	0.73609E 02	-0.11981E 01	-0.80284E 00	0.72650E 00	0.49965E-01
12	0.13458E 01	0.85889E 00	-0.28363E 00	0.72722E 02	-0.63639E 01	-0.86117E 01	0.79975E 00	0.50110E-01
13	0.17879E 01	0.49656E 00	-0.31588E 00	0.72183E 02	-0.30802E 01	-0.12865E 02	0.92675E 00	0.50134E-01
14	0.19986E 01	-0.17485E-03	-0.34534E 00	0.72121E 02	-0.17132E 00	-0.14707E 02	0.10732E 01	0.50180E-01
15	0.19417E 01	-0.49656E 00	-0.37338E 00	0.72541E 02	0.30659E 01	-0.15336E 02	0.12002E 01	0.50233E-01
16	0.16537E 01	-0.85841E 00	-0.3968[illegible]E 00	0.73802E 02	0.68469E 01	-0.11852E 02	0.12735E 01	0.49944E-01
17	0.12311E 01	-0.99944E 00	-0.41602E 00	0.74616E 02	0.46684E 00	-0.39539E 01	0.12735E 01	0.49988E-01
18	0.80607E 00	-0.87202E 00	-0.45176E 00	0.73228E 02	-0.56686E 01	-0.11218E 02	0.12002E 01	0.49670E-01
19	0.51385E 00	-0.50[illegible]4E 00	-0.48162E 00	0.70582E 02	-0.95169E 00	-0.13600E 02	0.10732E 01	0.49889E-01
20	0.44252E 00	0.[illegible]860E-02	-0.50274E 00	0.66164E 02	0.72852E 00	-0.11021E 02	0.92675E 00	0.49845E-01
21	0.66677E 00	0.50193E 00	-0.53343E 00	0.70318E 02	0.23641E 01	-0.11442E 02	0.79975E 00	0.49808E-01
22	0.11118E 01	0.87234E 00	-0.55762E 00	0.72544E 02	0.59830E 01	-0.77606E 01	0.72650E 00	0.49930E-01
23	0.16907E 01	0.99992E 00	-0.57659E 00	0.74487E 02	-0.20718E 00	-0.25328E 00	0.72650E 00	0.49988E-01
24	0.22655E 01	0.85931E 00	-0.61262E 00	0.72769E 02	-0.60573E 01	-0.83693E 01	0.79975E 00	0.50140E-01
25	0.27068E 01	0.49701E 00	-0.64485E 00	0.71396E 02	-0.26925E 01	-0.12505E 02	0.92675E 00	0.50128E-01
26	0.29169E 01	-0.74967E-04	-0.67375E 00	0.70719E 02	-0.10089E 00	-0.13655E 02	0.10732E 01	0.50153E-01
27	0.28605E 01	-0.49704E 00	-0.70213E 00	0.71423E 02	0.26063E 01	-0.14662E 02	0.12002E 01	0.50250E-01
28	0.25730E 01	-0.85892E 00	-0.72597E 00	0.73440E 02	0.63777E 01	-0.11701E 02	0.12735E 01	0.49963E-01
29	0.21508E 01	-0.10000E 01	-0.74510E 00	0.74723E 02	-0.51257E-01	-0.38496E 01	0.12735E 01	0.50032E-01
30	0.17264E 01	-0.87322E 00	-0.78094E 00	0.73972E 02	-0.66732E 01	-0.11228E 02	0.12002E 01	0.49758E-01
31	0.14354E 01	-0.50297E 00	-0.81230E 00	0.72540E 02	-0.28513E 01	-0.14973E 02	0.10732E 01	0.49830E-01
32	0.13774E 01	0.47022E-03	-0.83899E 00	0.71971E 02	0.37538E 00	-0.14420E 02	0.92675E 00	0.49874E-01
33	0.15883E 01	0.50342E 00	-0.86449E 00	0.72191E 02	0.31948E 01	-0.12542E 02	0.79975E 00	0.49881E-01
34	0.20319E 01	0.87294E 00	-0.88712E 00	0.73006E 02	0.63711E 01	-0.79029E 01	0.72650E 00	0.50017E-01
35	0.26099E 01	0.10004E 01	-0.90623E 00	0.74208E 02	0.17011E 00	-0.51008E 00	0.72650E 00	0.50048E-01
36	0.31836E 01	0.86088E 00	-0.94186E 00	0.71493E 02	-0.45928E 01	-0.81051E 01	0.79975E 00	0.50153E-01
37	0.36248E 01	0.49861E 00	-0.97089E 00	0.70162E 02	-0.12258E 01	-0.91913E 01	0.92675E 00	0.50052E-01
38	0.38352E 01	-0.21837E-03	-0.99851E 00	0.70098E 02	-0.16873E 00	-0.91691E 01	0.10732E 01	0.50051E-01
39	0.37781E 01	-0.49916E 00	-0.10269E 01	0.70260E 02	0.75553E 00	-0.10169E 02	0.12002E 01	0.50197E-01
40	0.34904E 01	-0.86187E 00	-0.10544E 01	0.71729E 02	0.37002E 01	-0.10430E 02	0.12735E 01	0.50069E-01
41	0.30636E 01	-0.10010E 01	-0.10748E 01	0.74104E 02	-0.93910E 00	-0.39854E 01	0.12735E 01	0.50054E-01
42	0.26458E 01	-0.87376E 00	-0.11105E 01	0.73695E 02	-0.71500E 01	-0.11544E 02	0.12002E 01	0.49767E-01
43	0.23552E 01	-0.50344E 00	-0.11419E 01	0.72452E 02	-0.32747E 01	-0.15897E 02	0.10732E 01	0.49815E-01
44	0.22973E 01	0.28201E-03	-0.11691E 01	0.71970E 02	0.20070E 00	-0.15619E 02	0.92675E 00	0.49865E-01
45	0.25076E 01	0.50367E 00	-0.11952E 01	0.71837E 02	0.33870E 01	-0.13790E 02	0.79975E 00	0.49887E-01
46	0.[illegible]504E 01	0.87384E 00	-0.12183E 01	0.72089E 02	0.71659E 01	-0.94124E 01	0.72650E 00	0.50023E-01
47	0.35276E 01	0.10045E 01	-0.12376E 01	0.72514E 02	0.39842E 01	-0.20946E 01	0.72650E 00	0.50012E-01
48	0.41031E 01	0.86696E 00	-0.12654E 01	0.71451E 02	0.82290E 00	-0.25169E 01	0.79975E 00	0.49994E-01
49	0.45452E 01	0.50016E 00	-0.12935E 01	0.	0.	0.	0.	0.

HELICOPTER WAKE VORTICITY DISTRIBUTION

NO. OF BLADES = 2   NO. OF AZIMUTH STATIONS = 12   NO. OF REV. OF WAKE = 4
LAMBDA = 0.20900E-02   MU = 0.14650E 00   ALPHA T = 2.620 DEG.   DELTA PSI = 30.000 DEG.

PSI = 30.000 DEGREES

BLADE NUMBER 2

STAT.	X	Y	Z	VX	VY	VZ	STRENGTH	CORE SIZE
1	-0.86603E 00	-0.50000E 00	0.	0.70464E 02	-0.62964E-01	-0.80246E 01	0.10732E 01	0.50000E-01
2	-0.92329E 00	0.20120E-03	-0.76579E-02	0.69828E 02	0.15778E 00	-0.47692E 01	0.92675E 00	0.49982E-01
3	-0.71201E 00	0.50051E 00	-0.31918E-01	0.70769E 02	0.66002E 00	-0.37145E 01	0.79975E 00	0.49996E-01
4	-0.26821E 00	0.86536E 00	-0.58218E-01	0.71832E 02	-0.66774E 00	-0.29612E 01	0.72650E 00	0.49997E-01
5	0.30945E 00	0.99534E 00	-0.84900E-01	0.72676E 02	-0.43561E 01	-0.23479E 01	0.72650E 00	0.49982E-01
6	0.88531E 00	0.85805E 00	-0.12027E 00	0.72008E 02	-0.70128E 01	-0.96513E 01	0.79975E 00	0.50120E-01
7	0.13277E 01	0.49638E 00	-0.15202E 00	0.71972E 02	-0.31496E 01	-0.13320E 02	0.92675E 00	0.50141E-01
8	0.15386E 01	-0.71446E-04	-0.18120E 00	0.72117E 02	-0.10740E 00	-0.15004E 02	0.10732E 01	0.50187E-01
9	0.14818E 01	-0.49632E 00	-0.20914E 00	0.72514E 02	0.32550E 01	-0.15595E 02	0.12002E 01	0.50236E-01
10	0.11937E 01	-0.85804E 00	-0.23263E 00	0.73641E 02	0.71723E 01	-0.12158E 02	0.12735E 01	0.49937E-01
11	0.77084E 00	-0.99865E 00	-0.25186E 00	0.74173E 02	0.11929E 01	-0.43540E 01	0.12735E 01	0.49930E-01
12	0.34511E 00	-0.86972E 00	-0.28631E 00	0.72059E 02	-0.35492E 01	-0.10537E 02	0.12002E 01	0.49841E-01
13	0.55491E-01	-0.50006E 00	-0.31378E 00	0.71641E 02	0.91356E-01	-0.10698E 02	0.10732E 01	0.50068E-01
14	0.96463E-02	-0.53742E-03	-0.34605E 00	0.82389E 02	-0.75989E-01	-0.13748E 02	0.92675E 00	0.50216E-01
15	0.20780E 00	0.49982E 00	-0.36714E 00	0.70307E 02	0.26231E 00	-0.94036E 01	0.79975E 00	0.49841E-01
16	0.65110E 00	0.87096E 00	-0.39272E 00	0.71605E 02	0.49071E 01	-0.75336E 01	0.72650E 00	0.49945E-01
17	0.12306E 01	0.99961E 00	-0.41209E 00	0.74259E 02	-0.42252E 00	-0.36822E 00	0.72650E 00	0.49974E-01
18	0.18058E 01	0.85914E 00	-0.44799E 00	0.72883E 02	-0.62027E 01	-0.83879E 01	0.79975E 00	0.50117E-01
19	0.22476E 01	0.49668E 00	-0.48036E 00	0.72016E 02	-0.29883E 01	-0.12737E 02	0.92675E 00	0.50133E-01
20	0.24580E 01	-0.16979E-03	-0.50975E 00	0.71673E 02	-0.17820E 00	-0.14506E 02	0.10732E 01	0.50172E-01
21	0.24013E 01	-0.49673E 00	-0.53783E 00	0.72214E 02	0.28992E 01	-0.15200E 02	0.12002E 01	0.50236E-01
22	0.21134E 01	-0.85864E 00	-0.56138E 00	0.73744E 02	0.66372E 01	-0.11767E 02	0.12735E 01	0.49951E-01
23	0.16910E 01	-0.99979E 00	-0.58049E 00	0.74759E 02	0.15942E 00	-0.38406E 01	0.12735E 01	0.50018E-01
24	0.12664E 01	-0.87285E 00	-0.61633E 00	0.73782E 02	-0.63767E 01	-0.11202E 02	0.12002E 01	0.49730E-01
25	0.97491E 00	-0.50230E 00	-0.64741E 00	0.71905E 02	-0.23961E 01	-0.14733E 02	0.10732E 01	0.49844E-01
26	0.91631E 00	0.81452E-03	-0.67345E 00	0.70946E 02	0.52060E 00	-0.13963E 02	0.92675E 00	0.49890E-01
27	0.11278E 01	0.50313E 00	-0.69945E 00	0.71662E 02	0.30430E 01	-0.12330E 02	0.79975E 00	0.49857E-01
28	0.15720E 01	0.87277E 00	-0.72232E 00	0.72943E 02	0.62556E 01	-0.77795E 01	0.72650E 00	0.50002E-01
29	0.21504E 01	0.10001E 01	-0.74130E 00	0.74468E 02	-0.74444E-01	-0.30184E 00	0.72650E 00	0.50009E-01
30	0.27248E 01	0.85970E 00	-0.77739E 00	0.72334E 02	-0.56959E 01	-0.84045E 01	0.79975E 00	0.50173E-01
31	0.31655E 01	0.49780E 00	-0.80848E 00	0.70493E 02	-0.19742E 01	-0.11366E 02	0.92675E 00	0.50094E-01
32	0.33757E 01	-0.10159E-03	-0.83661E 00	0.70112E 02	-0.85208E-01	-0.11743E 02	0.10732E 01	0.50109E-01
33	0.33190E 01	-0.49789E 00	-0.86552E 00	0.70615E 02	0.18808E 01	-0.13145E 02	0.12002E 01	0.50275E-01
34	0.30322E 01	-0.85958E 00	-0.89056E 00	0.72884E 02	0.57878E 01	-0.11389E 02	0.12735E 01	0.49992E-01
35	0.26104E 01	-0.10003E 01	-0.90982E 00	0.74510E 02	-0.31831E 00	-0.38900E 01	0.12735E 01	0.50042E-01
36	0.21862E 01	-0.87346E 00	-0.94563E 00	0.73940E 02	-0.68783E 01	-0.11360E 02	0.12002E 01	0.49767E-01
37	0.18955E 01	-0.50325E 00	-0.97707E 00	0.72697E 02	-0.30601E 01	-0.15198E 02	0.10732E 01	0.49823E-01
38	0.18376E 01	0.34138E-03	-0.10039E 01	0.72233E 02	0.28971E 00	-0.14723E 02	0.92675E 00	0.49870E-01
39	0.20482E 01	0.50351E 00	-0.10295E 01	0.72255E 02	0.32496E 01	-0.12841E 02	0.79975E 00	0.49890E-01
40	0.24915E 01	0.87314E 00	-0.10522E 01	0.72793E 02	0.65373E 01	-0.82635E 01	0.72650E 00	0.50031E-01
41	0.30690E 01	0.10012E 01	-0.10715E 01	0.73575E 02	0.94095E 00	-0.99266E 00	0.72650E 00	0.50072E-01
42	0.36427E 01	0.86338E 00	-0.11049E 01	0.70876E 02	-0.23106E 01	-0.64108E 01	0.79975E 00	0.50074E-01
43	0.40847E 01	0.49929E 00	-0.11327E 01	0.70446E 02	-0.58275E 00	-0.63174E 01	0.92675E 00	0.50014E-01
44	0.42954E 01	-0.32229E-03	-0.11596E 01	0.70790E 02	-0.20175E 00	-0.53059E 01	0.10732E 01	0.49999E-01
45	0.42386E 01	-0.50044E 00	-0.11865E 01	0.70953E 02	-0.38702E 00	-0.54283E 01	0.12002E 01	0.49988E-01
46	0.39497E 01	-0.86718E 00	-0.12138E 01	0.71374E 02	-0.10353E 01	-0.54391E 01	0.12735E 01	0.50023E-01
47	0.35278E 01	-0.10044E 01	-0.12410E 01	0.72709E 02	-0.39726E 01	-0.51344E 01	0.12735E 01	0.50064E-01
48	0.31049E 01	-0.87451E 00	-0.12763E 01	0.73216E 02	-0.78548E 01	-0.12033E 02	0.12002E 01	0.49759E-01
49	0.28146E 01	-0.50380E 00	-0.13071E 01	0.	0.	0.	0.	0.

HELICOPTER WAKE VORTICITY DISTRIBUTION

NO. OF BLADES = 2   NO. OF AZIMUTH STATIONS = 12   NO. OF REV. OF WAKE = 4

LAMBDA = 0.20300E-02   MU = 0.14650E 00   ALPHA 1 = 2.620 DEG.   DELTA PSI = 30.000 DEG.

PSI = 30.000 DEGREES

VELOCITIES AT OTHER POINTS

X	Y	Z	VX	VY	VZ
-0.10000E 01	0.30000E 00	-0.40000E 00	0.67669E 02	0.11893E 01	-0.25451E 01
-0.50000E 00	0.30000E 00	-0.40000E 00	0.66366E 02	0.64448E 01	-0.54331E 01
0.	0.30000E 00	-0.40000E 00	0.71123E 02	-0.18212E 01	-0.21935E 01
0.50000E 00	0.30000E 00	-0.40000E 00	0.74233E 02	-0.14831E 01	-0.95497E 01
0.10000E 01	0.30000E 00	-0.40000E 00	0.76297E 02	-0.31144E-02	-0.15102E 02

HELICOPTER WAKE VORTICITY DISTRIBUTION

NO. OF BLADES = 2 NO. OF AZIMUTH STATIONS = 12 NO. OF REV. OF WAKE = 4
LAMBDA = 0.20900E-02 MU = 0.14650E 00 ALPHA T = 2.620 DEG. DELTA PSI = 30.000 DEG.

PSI = 720.000 DEGREES

BLADE NUMBER 1

STAT.	X	Y	Z	VX	VY	VZ	STRENGTH	CORE SIZE
1	0.10000E 01	-0.13192E-05	0.	0.73802E 02	0.62160E-01	-0.22309E 02	0.10732E 01	0.50000E-01
2	0.94723E 00	-0.49549E 00	-0.24884E-01	0.74533E 02	0.38709E 01	-0.19550E 02	0.12002E 01	0.50145E-01
3	0.66470E 00	-0.84977E 00	-0.52407E-01	0.76012E 02	0.40185E 01	-0.21043E 02	0.12735E 01	0.49255E-01
4	0.23449E 00	-0.99296E 00	-0.10653E-01	0.71662E 02	0.27886E 01	-0.23402E 01	0.12735E 01	0.49995E-01
5	-0.19000E 00	-0.86523E 00	-0.27202E-01	0.71094E 02	0.44451E 00	-0.51412E 01	0.12002E 01	0.50079E-01
6	-0.48197E 00	-0.50347E 00	-0.30544E-01	0.70695E 02	-0.96689E 00	-0.39787E 01	0.10732E 01	0.49777E-01
7	-0.54709E 00	0.28829E-03	-0.22989E-01	0.68613E 02	-0.35762E 02	-0.30235E 01	0.92675E 00	0.49624E-01
8	-0.32817E 00	0.50627E 00	-0.30863E-01	0.71004E 02	0.10973E 01	-0.78051E 01	0.79975E 00	0.49971E-01
9	0.11976E 00	0.86792E 00	-0.36699E-01	0.70968E 02	0.18646E 01	-0.99287E 01	0.72650E 00	0.50115E-01
10	0.69818E 00	0.96077E 00	0.33340E-01	0.70527E 02	-0.10848E 02	0.25280E 01	0.72650E 00	0.48491E-01
11	0.12980E 01	0.87845E 00	-0.14989E 00	0.73121E 02	0.12583E 02	-0.58562E 01	0.79975E 00	0.49022E-01
12	0.17409E 01	0.47373E 00	-0.20575E 00	0.72934E 02	-0.67843E 00	-0.16447E 02	0.92675E 00	0.51316E-01
13	0.19515E 01	0.32006E-02	-0.23645E 00	0.72505E 02	0.48415E 00	-0.17434E 02	0.10732E 01	0.51741E-01
14	0.19025E 01	-0.45874E 00	-0.27565E 00	0.72844E 02	0.16719E 01	-0.16454E 02	0.12002E 01	0.51252E-01
15	0.16935E 01	-0.93812E 00	-0.29597E 00	0.85873E 02	0.99218E-01	-0.22491E 02	0.12735E 01	0.43423E-01
16	0.11802E 01	-0.93281E 00	-0.30956E-01	0.71577E 02	0.68779E 01	-0.21405E 01	0.12735E 01	0.50735E-01
17	0.77717E 00	-0.92083E 00	-0.18214E 00	0.75688E 02	-0.10972E 02	-0.89212E 01	0.12002E 01	0.48149E-01
18	0.48676E 00	-0.51027E 00	-0.18790E 00	0.71007E 02	-0.11679E-01	-0.16978E 02	0.10732E 01	0.51475E-01
19	0.40485E 00	-0.46315E-01	-0.12659E 00	0.67848E 02	0.74011E 01	-0.18656E 02	0.92675E 00	0.47754E-01
20	0.59581E 00	0.51632E 00	-0.16758E 00	0.70387E 02	0.12606E 01	-0.12836E 02	0.79975E 00	0.45996E-01
21	0.10733E 01	0.99065E 00	-0.10072E 00	0.73503E 02	0.54569E 01	0.74970E 01	0.72650E 00	0.49879E-01
22	0.16447E 01	0.80302E 00	-0.87670E-01	0.69957E 02	-0.62687E 01	-0.13029E 02	0.72650E 00	0.48209E-01
23	0.22465E 01	0.90357E 00	-0.30988E 00	0.73802E 02	0.31407E 01	-0.11021E 02	0.79975E 00	.50909E-01
24	0.26690E 01	0.44315E 00	-0.36539E 00	0.70579E 02	-0.51260E 00	-0.14458E 02	0.92675E 00	0.52662E-01
25	0.28798E 01	0.33694E-02	-0.41499E 00	0.70258E 02	0.64974E 00	-0.15160E 02	0.10732E 01	0.53517E-01
26	0.28235E 01	-0.42956E 00	-0.46937E 00	0.70299E 02	0.15460E 01	-0.16805E 02	0.12002E 01	0.54208E-01
27	0.25657E 01	-0.73060E 00	-0.43695E 00	0.72158E 02	0.16311E 01	-0.14870E 02	0.12735E 01	[illegible]
28	0.21526E 01	-0.90808E 00	-0.17486E 00	0.72550E 02	0.41351E 01	-0.43267E 01	0.12735E 01	0.51995E-01
29	0.17722E 01	-0.10027E 01	-0.29992E 00	0.76732E 02	-0.39961E 01	-0.12540E 01	0.12002E 01	0.43905E-01
30	0.14308E 01	-0.53207E 00	-0.47129E 00	0.74744E 02	-0.36847E 01	-0.14466E 02	0.10732E 01	0.47724E-01
31	0.13183E 01	0.96237E-02	-0.47099E 00	0.73100E 02	0.12771E 01	-0.15924E 02	0.92675E 00	0.47578E-01
32	0.15490E 01	0.56344E 00	-0.47752E 00	0.73798E 02	0.53434E 01	-0.11400E 02	0.79975E 00	0.46261E-01
33	0.20284E 01	0.10064E 01	-0.31901E 00	0.73968E 02	0.39212E 01	0.32824E 00	0.72650E 00	0.49526E-01
34	0.26242E 01	0.92922E 00	-0.25635E 00	0.72326E 02	-0.48654E 01	-0.14784E 01	0.72650E 00	0.48315E-01
35	0.31616E 01	0.76970E 00	-0.55395E 00	0.70451E 02	0.17753E 01	-0.11269E 02	0.79975E 00	0.52105E-01
36	0.35749E 01	0.45004E 00	-0.64006E 00	0.69240E 02	-0.99127E-01	-0.10190E 02	0.92675E 00	0.52332E-01
37	0.37798E 01	0.14937E-02	-0.69222E 00	0.69545E 02	0.25481E 00	-0.10246E 02	0.10732E 01	0.52484E-01
38	0.37223E 01	-0.44813E 00	-0.75332E 00	0.68917E 02	0.43937E 00	-0.11177E 02	0.12002E 01	0.54054E-01
39	0.34755E 01	-0.76267E 00	-0.74126E 00	0.69802E 02	-0.81113E 00	-0.12122E 02	0.12735E 01	0.47292E-01
40	0.30934E 01	-0.97206E 00	-0.51206E 00	0.73224E 02	-0.30681E 00	-0.39168E 01	0.12735E 01	0.50160E-01
41	0.26850E 01	-0.10220E 01	-0.66587E 00	0.75549E 02	-0.52882E 01	-0.63409E 01	0.12002E 01	0.44936E-01
42	0.23474E 01	-0.57754E 00	-0.81858E 00	0.74107E 02	-0.44500E 01	-0.12288E 02	0.10732E 01	0.45658E-01
43	0.22484E 01	0.17900E-01	-0.85018E 00	0.73184E 02	0.84096E 00	-0.14188E 02	0.92675E 00	0.46513E-01
44	0.24863E 01	0.59772E 00	-0.81442E 00	0.72733E 02	0.51148E 01	-0.11090E 02	0.79975E 00	0.47131E-01
45	0.29583E 01	0.10224E 01	-0.68925E 00	0.73123E 02	0.58761E 01	-0.41362E 01	0.72650E 00	0.49668E-01
46	0.35460E 01	0.96182E 00	-0.58146E 00	0.71752E 02	-0.90255E 00	0.56800E 00	0.72650E 00	0.49932E-01
47	0.40618E 01	0.79772E 00	-0.82672E 00	0.70705E 02	-0.97809E-01	-0.20428E 01	0.79975E 00	0.51929E-01
48	0.44787E 01	0.46736E 00	-0.87786E 00	0.70521E 02	-0.76439E-01	-0.31669E 01	0.92675E 00	0.51330E-01
49	0.46859E 01	-0.14668E-02	-0.91033E 00	0.	0.	0.	0.	0.

HELICOPTER WAKE VORTICITY DISTRIBUTION

NO. OF BLADES = 2 NO. OF AZIMUTH STATIONS = 12 NO. OF REV. OF WAKE = 4
LAMBDA = 0.20900E-02 MU = 0.14650E 00 ALPHA T = 2.620 DEG. DELTA PSI = 30.000 DEG.

PSI = 720.000 DEGREES

BLADE NUMBER 2

STAT.	X	Y	Z	VX	VY	VZ	STRENGTH	CORE SIZE
1	-0.10000E 01	0.13510E-05	0.	0.69474E 02	0.48261E-01	-0.67340E 01	0.92675E 00	0.50000E-01
2	-0.78946E 00	0.50056E 00	-0.63355E-02	0.69987E 02	0.63036E 00	-0.37369E 01	0.79975E 00	0.49987E-01
3	-0.34553E 00	0.36643E 00	-0.76117E-02	0.70762E 02	0.45596E-01	-0.22472E 01	0.72650E 00	0.50006E-01
4	0.23227E 00	0.99625E 00	0.67468E-02	0.70829E 02	-0.22705E 01	0.26045E 01	0.72650E 00	0.49687E-01
5	0.81543E 00	0.85568E 00	-0.51141E-01	0.75061E 02	-0.20262E 01	-0.22397E 02	0.79975E 00	0.49701E-01
6	0.12675E 01	0.48498E 00	-0.10350E 00	0.73448E 02	-0.17137E 01	-0.18256E 02	0.92675E 00	0.50743E-01
7	0.14798E 01	0.16138E-02	-0.12459E 00	0.73359E 02	0.39721E 00	-0.18078E 02	0.10732E 01	0.51027E-01
8	0.1[illegible]95E 01	-0.47404E 00	-0.15336E 00	0.73938E 02	0.24701E 01	-0.18901E 02	0.12002E 01	0.50788E-01
9	0.11733E 01	-0.83445E 00	-0.17155E 00	0.82162E 02	0.22288E 01	-0.15582E 02	0.12735E 01	0.46689E-01
10	0.70869E 00	-0.97039E 00	-0.22007E-01	0.72082E 02	0.50314E 01	0.94053E 00	0.12735E 01	0.50787E-01
11	0.29501E 00	-0.87110E 00	-0.83521E-01	0.72106E 02	-0.53891E 01	-0.18276E 02	0.12002E 01	0.50642E-01
12	0.80860E-02	-0.51915E 00	-0.10570E 00	0.71697E 02	0.28385E 00	-0.11531E 02	0.10732E 01	0.50902E-01
13	-0.76713E-01	-0.43692E-01	-0.53032E-01	0.74969E 02	-0.82527E 01	-0.32198E 01	0.92675E 00	0.47791E-01
14	0.13626E 00	0.51046E 00	-0.85090E-01	0.70929E 02	-0.42841E-01	-0.10546E 02	0.79975E 00	0.48448E-01
15	0.59085E 00	0.92055E 00	-0.10697E 00	0.72563E 02	0.13835E 02	-0.50037E 01	0.72650E 00	0.50194E-01
16	0.11647E 01	0.88535E 00	0.19018E-01	0.69935E 02	-0.12006E 02	-0.66691E 01	0.72650E 00	0.46820E-01
17	0.18025E 01	0.90305E 00	-0.21977E 00	0.75496E 02	0.52459E 01	-0.11709E 01	0.79975E 00	0.48914E-01
18	0.22100E 01	0.46302E 00	-0.29756E 00	0.71992E 02	-0.42523E 00	-0.15517E 02	0.92675E 00	0.51776E-01
19	0.24234E 01	0.42390E-02	-0.33253E 00	0.71881E 02	0.60505E 00	-0.16588E 02	0.10732E 01	0.52217E-01
20	0.23732E 01	-0.44778E 00	-0.38635E 00	0.72128E 02	0.11709E 01	-0.18286E 02	0.12002E 01	0.52648E-01
21	0.21374E 01	-0.78423E 00	-0.40411E 00	0.76799E 02	0.62695E-01	-0.17314E 02	0.12735E 01	0.43397E-01
22	0.16576E 01	-0.87547E 00	-0.83529E-01	0.71740E 02	0.69580E 01	-0.52760E 01	0.12735E 01	0.51403E-01
23	0.12794E 01	-0.97606E 00	-0.23386E 00	0.76486E 02	-0.78160E 01	-0.31960E 01	0.12002E 01	0.45373E-01
24	0.96435E 00	-0.50957E 00	-0.29600E 00	0.74419E 02	-0.24048E 01	-0.16752E 02	0.10732E 01	0.50510E-01
25	0.86005E 00	-0.30499E-01	-0.24079E 00	0.71215E 02	0.33137E 01	-0.17712E 02	0.92675E 00	0.47234E-01
26	0.10749E 01	0.53701E 00	-0.28882E 00	0.73338E 02	0.48817E 01	-0.14749E 02	0.79975E 00	0.45278E-01
27	0.15712E 01	0.99130E 00	-0.91256E-01	0.73582E 02	-0.35311E 01	0.63567E 01	0.72650E 00	0.50460E-01
28	0.21378E 01	0.85903E 00	-0.96509E-01	0.70868E 02	-0.81008E 01	-0.40697E 01	0.72650E 00	0.48038E-01
29	0.26981E 01	0.75808E 00	-0.39330E 00	0.71324E 02	0.35651E 00	-0.11929E 02	0.79975E 00	0.51636E-01
30	0.31241E 01	0.44320E 00	-0.49373E 00	0.69393E 02	-0.17284E 00	-0.12787E 02	0.92675E 00	0.52614E-01
31	0.33314E 01	0.28497E-02	-0.55546E 00	0.69492E 02	0.51129E 00	-0.13097E 02	0.10732E 01	0.52986E-01
32	0.32760E 01	-0.43832E 00	-0.61658E 00	0.69194E 02	0.90574E 00	-0.15062E 02	0.12002E 01	0.54372E-01
33	0.30295E 01	-0.74627E 00	-0.59064E 00	0.71817E 02	0.79967E 00	-0.14851E 02	0.12735E 01	0.46458E-01
34	0.26350E 01	-0.97193E 00	-0.34771E 00	0.73359E 02	0.10638E 01	-0.39406E 01	0.12735E 01	0.50592E-01
35	0.22222E 01	-0.10080E 01	-0.47857E 00	0.75793E 02	-0.45699E 01	-0.43411E 01	0.12002E 01	0.44393E-01
36	0.18796E 01	-0.55163E 00	-0.63960E 00	0.74131E 02	-0.44328E 01	-0.12761E 02	0.10732E 01	0.44697E-01
37	0.16176E 01	0.19016E-01	-0.69907E 00	0.71438E 02	0.10146E 01	-0.16678E 02	0.92675E 00	0.44273E-01
38	0.20144E 01	0.58415E 00	-0.64157E 00	0.73264E 02	0.53305E 01	-0.10359E 02	0.79975E 00	0.46807E-01
39	0.24931E 01	0.10141E 01	-0.51312E 00	0.73571E 02	0.48900E 01	-0.26615E 01	0.72650E 00	0.49359E-01
40	0.30898E 01	0.94413E 00	-0.41896E 00	0.72091E 02	-0.36492E 01	-0.10520E 01	0.72650E 00	0.49048E-01
41	0.36118E 01	0.78429E 00	-0.70398E 00	0.70050E 02	0.24461E 01	-0.73583E 01	0.79975E 00	0.52092E-01
42	0.40241E 01	0.45829E 00	-0.77051E 00	0.69737E 02	-0.24425E 00	-0.71663E 01	0.92675E 00	0.51912E-01
43	0.42299E 01	0.21168E-03	-0.81277E 00	0.70166E 02	-0.16432E-01	-0.66756E 01	0.10732E 01	0.51941E-01
44	0.41719E 01	-0.45979E 00	-0.86923E 00	0.69964E 02	0.78123E-01	-0.58770E 01	0.12002E 01	0.53535E-01
45	0.39169E 01	-0.77791E 00	-0.86575E 00	0.69553E 02	0.21451E 00	-0.41966E 01	0.12735E 01	0.48363E-01
46	0.35512E 01	-0.10155E 01	-0.67607E 00	0.72358E 02	-0.33111E 01	-0.31840E 01	0.12735E 01	0.50411E-01
47	0.31465E 01	-0.10349E 01	-0.84171E 00	0.75043E 02	-0.62990E 01	-0.74135E 01	0.12002E 01	0.44942E-01
48	0.28123E 01	-0.58832E 00	-0.99537E 00	0.73264E 02	-0.43889E 01	-0.12853E 02	0.10732E 01	0.45508E-01
49	0.27344E 01	0.14390E-01	-0.10249E 01	0.	0.	0.	0.	0.

HELICOPTER WAKE VORTICITY DISTRIBUTION

NO. OF BLADES = 2 NO. OF AZIMUTH STATIONS = 12 NO. OF REV. OF WAKE = 4

LAMBDA = 0.20900E-02 MU = 0.14650E 00 ALPHA T = 2.620 DEG. DELTA PSI = 30.000 DEG.

PSI = 720.000 DEGREES

VELOCITIES AT OTHER POINTS

X	Y	Z	VX	VY	VZ
-0.10000E 01	0.30000E 00	-0.40000E 00	0.67253E 02	0.80046E 00	-0.29231E 01
-0.50000E 00	0.30000E 00	-0.40000E 00	0.66243E 02	0.55386E 01	-0.66757E 01
0.	0.30000E 00	-0.40000E 00	0.70195E 02	-0.21054E 01	-0.68770E 01
0.50000E 00	0.30000E 00	-0.40000E 00	0.54424E 02	0.22732E 01	-0.84857E 01
0.10000E 01	0.30000E 00	-0.40000E 00	0.64762E 02	0.50409E 01	-0.12683E 02

TABULATION OF SURFACE-ELEMENT VERTEX
COORDINATES FOR A UH-1B FUSELAGE

ELEMENT No. m	x_{1m}	y_{1m}	z_{1m}	x_{2m}	y_{2m}	z_{2m}	x_{3m}	y_{3m}	z_{3m}	x_{4m}	y_{4m}	z_{4m}
1	-.519	.019	-.425	-.519	.013	-.378	-.519	0	-.376	-.519	0	-.425
2	-.519	.042	-.422	-.519	.032	-.382	-.519	.013	-.378	-.519	.019	-.425
3	-.519	.049	-.414	-.519	.049	-.403	-.519	.032	-.382	-.519	.042	-.422
4	-.498	0	-.452	-.498	.038	-.448	-.519	.019	-.425	-.519	0	-.425
5	-.498	.038	-.448	-.498	.076	-.437	-.519	.042	-.422	-.519	.019	-.425
6	-.498	.076	-.437	-.498	.091	-.422	-.519	.049	-.414	-.519	.042	-.422
7	-.498	.091	-.422	-.498	.097	-.399	-.519	.049	-.403	-.519	.049	-.414
8	-.498	.097	-.399	-.498	.057	-.363	-.519	.032	-.382	-.519	.049	-.403
9	-.498	.057	-.363	-.498	.025	-.351	-.519	.013	-.378	-.519	.032	-.382
10	-.498	.025	-.351	-.498	0	-.346	-.519	0	-.376	-.519	.013	-.378
11	-.445	0	-.469	-.445	.051	-.463	-.498	.038	-.448	-.498	0	-.452
12	-.445	.051	-.463	-.445	.106	-.448	-.498	.076	-.437	-.498	.038	-.448
13	-.445	.106	-.448	-.445	.129	-.427	-.498	.091	-.422	-.498	.076	-.437
14	-.445	.129	-.427	-.445	.133	-.397	-.498	.097	-.399	-.498	.091	-.422
15	-.445	.133	-.397	-.445	.083	-.340	-.498	.057	-.363	-.498	.097	-.399
16	-.445	.083	-.340	-.445	.036	-.325	-.498	.025	-.351	-.498	.057	-.363
17	-.445	.036	-.325	-.445	0	-.323	-.498	0	-.346	-.498	.025	-.351
18	-.405	0	-.471	-.405	.051	-.467	-.445	.051	-.463	-.445	0	-.469
19	-.405	.051	-.467	-.405	.110	-.452	-.445	.106	-.448	-.445	.051	-.463
20	-.405	.110	-.452	-.405	.136	-.429	-.445	.129	-.427	-.445	.106	-.448
21	-.405	.136	-.429	-.405	.148	-.399	-.445	.133	-.397	-.445	.129	-.427
22	-.405	.148	-.399	-.405	.123	-.340	-.445	.083	-.340	-.445	.133	-.397
23	-.405	.123	-.340	-.405	.095	-.302	-.445	.036	-.325	-.445	.083	-.340
24	-.405	.095	-.302	-.405	.078	-.289	-.445	.027	-.325	-.445	.036	-.325
25	-.405	.078	-.289	-.405	.061	-.281	-.445	.019	-.323	-.445	.027	-.325
26	-.405	.061	-.281	-.405	.027	-.279	-.445	.008	-.323	-.445	.019	-.323
27	-.405	.027	-.279	-.405	0	-.278	-.445	0	-.323	-.445	.008	-.323
28	-.366	0	-.471	-.366	.053	-.471	-.405	.051	-.467	-.405	0	-.471
29	-.366	.053	-.471	-.366	.114	-.456	-.405	.110	-.452	-.405	.051	-.467
30	-.366	.114	-.456	-.366	.140	-.433	-.405	.136	-.429	-.405	.110	-.452
31	-.366	.140	-.433	-.366	.153	-.404	-.405	.148	-.399	-.405	.136	-.429
32	-.366	.153	-.404	-.366	.134	-.340	-.405	.123	-.340	-.405	.148	-.399
33	-.366	.134	-.340	-.366	.129	-.287	-.405	.095	-.302	-.405	.123	-.340
34	-.366	.129	-.287	-.366	.117	-.261	-.405	.078	-.289	-.405	.095	-.302
35	-.366	.117	-.261	-.366	.097	-.245	-.405	.061	-.281	-.405	.078	-.289
36	-.366	.097	-.245	-.366	.045	-.230	-.405	.027	-.279	-.405	.061	-.281
37	-.366	.045	-.230	-.366	0	-.228	-.405	0	-.278	-.405	.027	-.279
38	-.294	0	-.471	-.294	.053	-.471	-.366	.053	-.471	-.366	0	-.471
39	-.294	.053	-.471	-.294	.114	-.458	-.366	.114	-.456	-.366	.053	-.471
40	-.294	.114	-.458	-.294	.140	-.437	-.366	.140	-.433	-.366	.114	-.456
41	-.294	.140	-.437	-.294	.155	-.406	-.366	.153	-.404	-.366	.140	-.433
42	-.294	.155	-.406	-.294	.142	-.340	-.366	.134	-.340	-.366	.153	-.404
43	-.294	.142	-.340	-.294	.136	-.285	-.366	.129	-.287	-.366	.134	-.340
44	-.294	.136	-.285	-.294	.133	-.255	-.366	.117	-.261	-.366	.129	-.287
45	-.294	.133	-.255	-.294	.110	-.230	-.366	.097	-.245	-.366	.117	-.261

TABULATION OF SURFACE-ELEMENT VERTEX
COORDINATES FOR A UH-IB FUSELAGE (Cont'd)

ELEMENT No. m	x_{1m}	y_{1m}	z_{1m}	x_{2m}	y_{2m}	z_{2m}	x_{3m}	y_{3m}	z_{3m}	x_{4m}	y_{4m}	z_{4m}
46	-.294	.110	-.230	-.294	.051	-.219	-.366	.045	-.230	-.366	.097	-.245
47	-.294	.051	-.219	-.294	0	-.217	-.366	0	-.228	-.366	.045	-.230
48	-.217	0	-.471	-.217	.053	-.471	-.294	.053	-.471	-.294	0	-.471
49	-.217	.053	-.471	-.217	.117	-.461	-.294	.114	-.458	-.294	.053	-.471
50	-.217	.117	-.461	-.217	.148	-.440	-.294	.140	-.437	-.294	.114	-.458
51	-.217	.148	-.440	-.217	.159	-.408	-.294	.155	-.406	-.294	.140	-.437
52	-.217	.159	-.408	-.217	.155	-.340	-.294	.142	-.340	-.294	.155	-.406
53	-.217	.155	-.340	-.217	.150	-.279	-.294	.136	-.285	-.294	.142	-.340
54	-.217	.150	-.279	-.217	.144	-.247	-.294	.133	-.255	-.294	.136	-.285
55	-.217	.144	-.247	-.217	.121	-.221	-.294	.110	-.230	-.294	.133	-.255
56	-.217	.121	-.221	-.217	.055	-.209	-.294	.051	-.219	-.294	.110	-.230
57	-.217	.055	-.209	-.217	0	-.209	-.294	0	-.217	-.294	.051	-.219
58	-.084	0	-.471	-.084	.053	-.471	-.217	.053	-.471	-.217	0	-.471
59	-.084	.053	-.471	-.084	.121	-.467	-.217	.117	-.461	-.217	.053	-.471
60	-.084	.121	-.467	-.084	.159	-.452	-.217	.148	-.440	-.217	.117	-.461
61	-.084	.159	-.452	-.084	.178	-.420	-.217	.159	-.408	-.217	.148	-.440
62	-.084	.178	-.420	-.084	.178	-.340	-.217	.155	-.340	-.217	.159	-.408
63	-.084	.178	-.340	-.084	.170	-.270	-.217	.150	-.279	-.217	.155	-.340
64	-.084	.170	-.270	-.084	.161	-.236	-.217	.144	-.247	-.217	.150	-.279
65	-.084	.161	-.236	-.084	.125	-.217	-.217	.121	-.221	-.217	.144	-.247
66	-.084	.125	-.217	-.084	.055	-.209	-.217	.055	-.209	-.217	.121	-.221
67	-.084	.055	-.209	-.084	0	-.209	-.217	0	-.209	-.217	.055	-.209
68	.066	0	-.471	.066	.053	-.471	-.084	.053	-.471	-.084	0	-.471
69	.066	.053	-.471	.066	.144	-.458	-.084	.121	-.467	-.084	.053	-.471
70	.066	.114	-.458	.066	.138	-.439	-.084	.159	-.452	-.084	.121	-.467
71	.066	.138	-.439	.066	.152	-.408	-.084	.178	-.420	-.084	.159	-.452
72	.066	.152	-.408	.066	.150	-.340	-.084	.178	-.340	-.084	.178	-.420
73	.066	.150	-.340	.066	.142	-.283	-.084	.170	-.270	-.084	.178	-.340
74	.066	.142	-.283	.066	.127	-.259	-.084	.161	-.236	-.084	.170	-.270
75	.066	.127	-.259	.066	.098	-.242	-.084	.125	-.217	-.084	.161	-.236
76	.066	.098	-.242	.066	.053	-.232	-.084	.055	-.209	-.084	.125	-.217
77	.066	.053	-.232	.066	0	-.230	-.084	0	-.209	-.084	.055	-.209
78	.241	0	-.444	.241	.038	-.433	.066	.053	-.471	.066	0	-.471
79	.241	.038	-.433	.241	.057	-.403	.066	.114	-.458	.066	.053	-.471
80	.241	.057	-.403	.241	.061	-.384	.066	.138	-.439	.066	.114	-.458
81	.241	.061	-.384	.241	.062	-.368	.066	.152	-.408	.066	.138	-.439
82	.241	.062	-.368	.241	.061	-.340	.066	.150	-.340	.066	.152	-.408
83	.241	.061	-.340	.241	.053	-.317	.066	.142	-.283	.066	.150	-.340
84	.241	.053	-.317	.241	.049	-.310	.066	.127	-.259	.066	.142	-.283
85	.241	.049	-.310	.241	.040	-.298	.066	.098	-.242	.066	.127	-.259
86	.241	.040	-.298	.241	.021	-.291	.066	.053	-.232	.066	.098	-.242
87	.241	.021	-.291	.241	0	-.289	.066	0	-.230	.066	.053	-.232
88	.269	0	-.410	.269	.025	-.401	.241	.038	-.433	.241	0	-.444
89	.269	.025	-.401	.269	.030	-.368	.241	.057	-.403	.241	.038	-.433
90	.269	.030	-.368	.269	.028	-.353	.241	.061	-.384	.241	.057	-.403

TABULATION OF SURFACE-ELEMENT VERTEX
COORDINATES FOR A UH-IB FUSELAGE (Cont'd)

ELEMENT No. m	x_{1m}	y_{1m}	z_{1m}	x_{2m}	y_{2m}	z_{2m}	x_{3m}	y_{3m}	z_{3m}	x_{4m}	y_{4m}	z_{4m}
91	.269	.028	-.353	.269	.019	-.333	.241	.061	-.340	.241	.062	-.368
92	.269	.019	-.333	.269	.011	-.329	.241	.049	-.310	.241	.053	-.317
93	.269	.011	-.329	.269	.006	-.327	.241	.021	-.291	.241	.040	-.298
94	.269	.006	-.327	.269	0	-.327	.241	0	-.289	.241	.021	-.291
95	.269	0	-.327	.269	.019	-.333	.269	.025	-.401	.269	0	-.410
96	.269	.019	-.333	.269	.028	-.368	.269	.030	-.368	.269	.025	-.401

REFERENCES

1. Crimi, P., Theoretical Prediction of the Flow in the Wake of a Helicopter Rotor, Part 1 - Development of Theory and Results of Computations, CAL Report BB-1994-S-1, September 1965.

2. Fradenburgh, E. A., Flow Field Measurements for a Hovering Rotor Near the Ground, Paper Presented at AHS 5th Annual Western Forum, Los Angeles, California, September 25-26, 1958.

3. Brady, W. G., and Crimi, P., Representation of Propeller Wakes by Systems of Finite Core Vortices, CAL Report BB-1665-S-2, February 1965.

4. Glauert, H., The Elements of Aerofoil and Airscrew Theory, MacMillan Company, New York, 1943.

5. Piziali, R. A., and DuWaldt, F. A., A Method for Computing Rotary Wing Airload Distribution in Forward Flight, CAL Report BB-1495-A-1, TCREC TR 62-44, November 1962.

6. Castles, W., and DeLeeuw, J., The Normal Component of the Induced Velocity in the Vicinity of a Lifting Rotor and Some Examples of Its Application, NACA TR 1184, 1954.

7. Lamb, H., Hydrodynamics, Sixth Edition, Dover, New York 1945.

8. Hess, J. and Smith, A., Calculation of Nonlifting Potential Flow About Arbitrary Three-Dimensional Bodies, J. Ship Research, Vol. 8, No. 2, September 1964.

APPENDIX I

OPERATIONAL INFORMATION FOR THE MAIN PROGRAM

This program is written in FORTRAN IV, with the exception of subroutine CLEAR, which is written in MAP. This routine is used to initialize storages to be zero.

INPUTS

CARD 1	NB:	Number of blades, N_B
	NRW:	Number of Revolutions of wake per blade, N_R
	NA:	Number of azimuth stations, N_A
	NPNCH:	Punch option. If zero, no cards are punched at the end of a run. If not zero, all wake point coordinates and core sizes at the final azimuth position are punched on cards.
	NOPT:	If zero, the initial wake configuration is computed. If not zero, initial wake configuration is read in.
	NTAPE:	If not zero, wake point coordinates and velocities are saved on utility Tape 4.
	NPRINT:	If NPRINT = 1, coordinates and velocities for each wake point are printed; if NPRINT = 2, those for every other point are printed; if 3, every third; etc.
	LNCT:	Number of lines desired per page of output.
	NFPT:	Number of fuselage points, N_f
	NXPT:	Number of points off the wake for which velocities are to be calculated.
	NPINT:	Output is produced at intervals of NPINT steps; i. e., if NPINT = 1, the data for each azimuth position is printed.

CARD 2	PSI0:	Initial position of blade 1, ψ_{init}, degrees.
	REV:	Number of revolutions of rotor for which calculations are to be performed, N_{RV}
	XLAM:	λ
	XMU:	μ
	ALPHAT:	α_T (degrees)
	FACTR:	Factor applied to V_{z_∞}, K_f
	RB:	R/b
CARD 3, 4,	GAMB:	Strengths of blade 1; NA of them.
	A1:	Core sizes at Blade 1; (NA of them).
	A:	Initial core sizes; (NRW)(NA)(NB) of them.

Fuselage Data: Four cards for each point; (4)(NFPT) cards in all. These are punched by the Fuselage Program.

Card 1	XBAR	YBAR	ZBAR	SIGX	SIGZ	
	$\bar{x}$	$\bar{y}$	$\bar{z}$	σ_x	σ_z	
Card 2	XI1	XI2	XI3	XI4	ETA1	ETA2
	ξ_1	ξ_2	ξ_3	ξ_4	η_1	η_2
Card 3	ETA3	ETA4	D1	D2	D3	D4
	η_3	η_4	d_1	d_2	d_3	d_4
Card 4	XLE	XME	XNE	XLZ	XMZ	XNZ
	λ_η	μ_η	ν_η	λ_ζ	μ_ζ	ν_ζ

Coordinates of points off the wake at which velocities are to be computed NXPT points in all (up to three sets of coordinates per card):

XIPT	YIPT	ZIPT
x	y	z

Initial Wake Configuration - Read in only if NOPT is not zero.

X:	(NRW)(NB)(NA) of them.
Y:	(NRW)(NB)(NA) of them.
Z:	(NRW)(NB)(NA) of them.

A listing of the program is given on the pages which follow.

```
$IBFTC ZZHWV   LIST,REF
C     CALCULATION OF THE WAKE VORTICITY DISTRIBUTION FOR A HELICOPTER
      COMMON X(340,4),Y(340,4),Z(340,4),U(340,4),V(340,4),W(340,4),
     1       GAMA(340,4),SEG(340,4),GAMB1(100),A1(100),A(340,4),PI,RAD,
     2       VMP,XMCL,XMSL,NB,NRW,NA,NW,NOPT,NTAPE,NPRINT,NDVCH,PSIO,
     3       XMU,XLAM,ALPHAT,PINT,PSIF,XNA,DPSI,NB1,NW1,XNW,XNB,TPNB,
     4       SAT,CAT,C1,C2,PSI,TPI,XI,T1,T2,XJ,NPS,JPS,IPS,IPS1,XXX,YYY,
     5       ZZZ,IST,IND,IFLG,SIG1,SIG2,SIG3,GGG,DEN,XNU1,XNU2,XNU3,IR1,
     6       XMX,XMY,XMZ,SIG4,SIG5,RR,SQI1,SF,SQI,SG,BF,LPS,SEG1,SEG2,
     7       SUM,LNCT,XIPT(400),YIPT(400),ZIPT(400),VX(400),VY(400),
     8       VZ(400),VXF(400),VYF(400),VZF(400),NXPT,NAB,FACTR,RB
      COMMON /FUSE/ XBAR(100),YBAR(100),ZBAR(100),SIGX(100),SIGZ(100),
     1       XI1(100),XI2(100),XI3(100),XI4(100),ETA1(100),ETA2(100),
     2       ETA3(100),ETA4(100),XLE(100),XME(100),XNE(100),XLZ(100),
     3       XXZ(100),XNZ(100),NFPT,RJ(4),EJ(4),HJ(4),EMJ(4),D1(100),
     4       D2(100),D3(100),D4(100),VXINF,VYINF,VZINF,UF,VF,WF
      DIMENSION GAMB(100)
      EQUIVALENCE(GAMB1,GAMB)
    1 CALL CLEAR(X,NAB)
      CALL CLEAR(XBAR,WF)
      PI = 3.1415926536
      RAD = .0174532925
      TPI = 2.0*PI
      READ 1000,NB,NRW,NA,NPNCH,NOPT,NTAPE,NPRINT,LNCT,NFPT,NXPT,NPINT,
     1          NDVCH
 1000 FORMAT(12I6)
      CALL DVDCHK(NDVCH)
      IF(NTAPE.LT.0) REWIND 4
      READ 1001,PSIO,REV,XLAM,XMU,ALPHAT,FACTR,RB
 1001 FORMAT(9F8.6)
      READ 1001,(GAMB1(I),I=1,NA)
      READ 1001,(A1(I),I=1,NA)
      NB1 = NB
      NW = NRW*NA
      NW1 = NW+1
      NAB = NB*NA
      XNA = NA
      DPSI = 2.0*PI/XNA
      XNW = NW
      XNB = NB
      SAT = SIN(ALPHAT*RAD)
      CAT = COS(ALPHAT*RAD)
      C1 = XMU*CAT
      C2 = (XMU*SAT+XLAM)
      C3 = XMU*SAT+SQRT(XLAM*XNB/2.0)
      XMCL = C1/XLAM
      XMSL = XMU*SAT/XLAM
      VXINF = XMCL
      VZINF = -FACTR*(XMSL+SQRT(.5*XNB/XLAM))
      TMP = RB*DPSI
      TMP1 = SQRT(TMP*(TMP+2.0))
      FRB = (TMP-TMP1+ALOG(1.0+TMP+TMP1))/DPSI
      READ 1001,((A(I,J),I=1,NW),J=1,NB1)
      IF(NFPT.EQ.0) GO TO 100
      READ 1003,(XBAR(I),YBAR(I),ZBAR(I),SIGX(I),SIGZ(I),BLNK,XI1(I),
     1          XI2(I),XI3(I),XI4(I),ETA1(I),ETA2(I),ETA3(I),ETA4(I),
```

```
     2          D1(I),D2(I),D3(I),D4(I),XLE(I),XME(I),XNE(I),XLZ(I),
     3          XXZ(I),XNZ(I),I=1,NFPT)
1003 FORMAT(6E12.5)
 100 IF(NXPT.EQ.0) GO TO 103
     READ 1001,(XIPT(I),YIPT(I),ZIPT(I),I=1,NXPT)
 101 DO 102  I=1,NXPT
     CALL FUSLGE(XIPT(I),YIPT(I),ZIPT(I),VXF(I),VYF(I),VZF(I))
 102 CONTINUE
 103 PSIF = PSIO+360.0*REV
     CALL IDOUT
     NCT = 0
     TPNB = 2.0*PI/XNB
     PSI = PSIO*RAD
     PSIO = PSI
     PSIF = PSIF*RAD+0.05
     IF(NOPT.EQ.0) GO TO 3
   2 READ 1003,((X(I,J),I=1,NW1),J=1,NB)
     READ 1003,((Y(I,J),I=1,NW1),J=1,NB)
     READ 1003,((Z(I,J),I=1,NW1),J=1,NB)
     GO TO 7
   3 DO 6  I=1,NW1
     XI = FLOAT(I-1)*DPSI
     T1 = XI*C1
     T3 = XI*C3
   4 DO 5  J=1,NB
     XJ = FLOAT(J-1)*TPNB
     X(I,J) = COS(PSIO+XJ-XI)+T1
     Y(I,J) = SIN(PSIO+XJ-XI)
     Z(I,J) = -T3
   5 CONTINUE
   6 CONTINUE
   7 NPS = AMOD(PSIO,2.0*PI)/DPSI+1.5
     IF (NPS.GT.NA) NPS = 1
     DO 9  J=1,NB
     JPS = MOD(NPS+(NA*(J-1))/NB+NAB,NA)
     IF (JPS.EQ.0) JPS = NA
     IPS1 = JPS
     DO 8  I=1,NW
     IPS = IPS1
     IPS1 = IPS-1
     IF(IPS1.EQ.0) IPS1 = NA
     GAMA(I,J) = (GAMB(IPS)+GAMB(IPS1))/2.0
   8 CONTINUE
   9 CONTINUE
  10 DO 12  J=1,NB1
     DO 11  I=1,NW
     SEG(I,J) = SQRT((X(I,J)-X(I+1,J))**2+(Y(I,J)-Y(I+1,J))**2+(Z(I,J)-
    1          Z(I+1,J))**2)
  11 CONTINUE
  12 CONTINUE
  13 DO 29  I=1,NW
     DO 28 J=1,NB1
     XXX = X(I,J)
     YYY = Y(I,J)
     ZZZ = Z(I,J)
     U(I,J) = 0.0
```

```
      V(I,J) = 0.0
      W(I,J) = 0.0
   14 DO 25  L=1,NB1
      IST = 1
      IND = NW
      IFLG = 1
      IF (L.NE.J) GO TO 16
      IND = I-2
      IFLG = 2
      IF (IND.GT.0) GO TO 16
   15 IST = I+1
      IND = NW
      IFLG = 1
      IF (IST.GT.NW) GO TO 18
   16 SIG2 = SQRT((XXX-X(IST,L))**2+(YYY-Y(IST,L))**2+(ZZZ-Z(IST,L))**2)
      DO 17 IR=IST,IND
      SIG1 = SIG2
      SIG2 = SQRT((XXX-X(IR+1,L))**2+(YYY-Y(IR+1,L))**2+(ZZZ-Z(IR+1,L))
     1       **2)
      SEGSQ = SEG(IR,L)**2
      HM1 = SIG1**2+SIG2**2
      IF(HM1.GT.SEGSQ)GO TO 160
      HM2 = .25*((SIG1+SIG2)**2-SEGSQ)*(SEGSQ-(SIG1-SIG2)**2)/SEGSQ
      IF(HM2.GT.A(IR,L)**2)GO TO 160
      GGG = GAMA(IR,L)/SEG(IR,L)
      GO TO 161
  160 GGG = GAMA(IR,L)*(SIG1+SIG2)/(SIG1*SIG2*((SIG1+SIG2)**2-SEGSQ))
  161 XNU1 = (YYY-Y(IR+1,L))*(Z(IR,L)-Z(IR+1,L))-(ZZZ-Z(IR+1,L))*
     1        (Y(IR,L)-Y(IR+1,L))
      XNU2 = (ZZZ-Z(IR+1,L))*(X(IR,L)-X(IR+1,L))-(XXX-X(IR+1,L))*
     1       (Z(IR,L)-Z(IR+1,L))
      XNU3 = (XXX-X(IR+1,L))*(Y(IR,L)-Y(IR+1,L))-(YYY-Y(IR+1,L))*
     1       (X(IR,L)-X(IR+1,L))
      U(I,J) = U(I,J)+XNU1*GGG
      V(I,J) = V(I,J)+XNU2*GGG
      W(I,J) = W(I,J)+XNU3*GGG
   17 CONTINUE
      GO TO (18,15),IFLG
   18 IF (L.NE.J) GO TO 25
      IR1 = I-1
      IF (I.EQ.1) IR1 = 1
      XMX = (Y(IR1,L)-Y(IR1+1,L))*(Z(IR1+1,L)-Z(IR1+2,L))-(Y(IR1+1,L)-
     1      Y(IR1+2,L))*(Z(IR1,L)-Z(IR1+1,L))
      XMY = (Z(IR1,L)-Z(IR1+1,L))*(X(IR1+1,L)-X(IR1+2,L))-(Z(IR1+1,L)-
     1      Z(IR1+2,L))*(X(IR1,L)-X(IR1+1,L))
      XMZ = (X(IR1,L)-X(IR1+1,L))*(Y(IR1+1,L)-Y(IR1+2,L))-(X(IR1+1,L)-
     1      X(IR1+2,L))*(Y(IR1,L)-Y(IR1+1,L))
      SIG4 = SEG(IR1+1,L)
      SIG3 = SEG(IR1,L)
      SIG5 = SQRT((X(IR1+2,L)-X(IR1,L))**2+(Y(IR1+2,L)-Y(IR1,L))**2+
     1       (Z(IR1+2,L)-Z(IR1,L))**2)
      DEN = (SIG3+SIG4-SIG5)*(SIG3+SIG4+SIG5)*(SIG4+SIG5-SIG3)*(SIG3+
     1      SIG5-SIG4)
      IF (DEN.EQ.0.0) GO TO 25
      IF(DEN.LT.0.0)WRITE(6,1002)I,J,SIG3,SIG4,SIG5
 1002 FORMAT(2X43HDENUMINATOR NEGATIVE FOR R COMPUTATION  I =I3,3X3HJ =
```

```
     1        I3,3X6HSIG3 =E16.8,3X6HSIG4 =E16.8,3X6HSIG5 =E16.8 )
      RR = SIG3*SIG4*SIG5/SQRT(ABS(DEN))
      SQI1 = SQRT((2.0*RR-SIG3)*(2.0*RR+SIG3))
      IF (SIG3**2.LE.SIG4**2+SIG5**2) GO TO 19
      SF = (2.0*RR+SQI1)/SIG3
      GO TO 20
   19 SF = (2.0*RR-SQI1)/SIG3
      IF(SF.EQ.0.0) SF = 1.0E-20
   20 SQI = SQRT((2.0*RR-SIG4)*(2.0*RR+SIG4))
      IF (SIG4**2.LE.SIG3**2+SIG5**2) GO TO 21
      SG = (2.0*RR+SQI)/SIG4
      GO TO 22
   21 SG = (2.0*RR-SQI)/SIG4
      IF(SG.EQ.0.0) SG = 1.0E-20
   22 IF (I.EQ.1) GO TO 23
      BF = (GAMA(IR1,J)*(ALOG(8.0*SF/A(IR1,J))+.25)+GAMA(I,J)*(ALOG(8.0*
     1        SG/A(I,J))+.25))/(4.0*RR*SQRT(XMX**2+XMY**2+XMZ**2))
      GO TO 24
   23 BF = (GAMA(I,J)*(ALOG(8.0*SF/A(I,J))+.25))/(4.0*RR*SQRT(XMX**2+
     1        XMY**2+XMZ**2))
   24 U(I,J) = U(I,J)+XMX*BF
      V(I,J) = V(I,J)+XMY*BF
      W(I,J) = W(I,J)+XMZ*BF
   25 CONTINUE
      SIG1 = SQRT(XXX**2+YYY**2+ZZZ**2)
   26 DO 27  L=1,NB
      LPS = MOD(NPS+(NA*(L-1))/NB+NAB,NA)
      IF(LPS.EQ.0) LPS = NA
      IF(I.EQ.1.AND.L.EQ.J)GO TO 260
      PSIBK = FLOAT(LPS-1)*DPSI
      SINPSI = SIN(PSIBK)
      COSPSI = COS(PSIBK)
      RMH2 = (XXX-COSPSI)**2+(YYY-SINPSI)**2+ZZZ**2
      IF (RMH2+SIG1**2.GT.1.0) GO TO 258
      RMH = SQRT(RMH2)
      H2 = .25*((SIG1+RMH)**2-1.0)*(1.0-(SIG1-RMH)**2)
      IF (H2*RB**2.GT.1.0) GO TO 258
      HH = SQRT(H2)
      XHT = XXX*(COSPSI**2+SINPSI**2/(HH*RB))-YYY*SINPSI*COSPSI*(1.0/
     1        (HH*RB)-1.0)
      YHT = YYY*(SINPSI**2+COSPSI**2/(HH*RB))-XXX*SINPSI*COSPSI*(1.0/
     1        (HH*RB)-1.0)
      ZHT = ZZZ/(HH*RB)
      XNU1 = -YHT*Z(1,L)+ZHT*Y(1,L)
      XNU2 = -ZHT*X(1,L)+XHT*Z(1,L)
      XNU3 =-XHT*Y(1,L)+YHT*X(1,L)
      SIG2 = SQRT((XHT-X(1,L))**2+(YHT-Y(1,L))**2+(ZHT-Z(1,L))**2)
      GO TO 259
  258 XNU1 = -YYY*Z(1,L)+ZZZ*Y(1,L)
      XNU2 = -ZZZ*X(1,L)+XXX*Z(1,L)
      XNU3 = -XXX*Y(1,L)+YYY*X(1,L)
      SIG2 = SQRT((XXX-X(1,L))**2+(YYY-Y(1,L))**2+(ZZZ-Z(1,L))**2)
  259 GGG = GAMB(LPS)*(SIG1+SIG2)/(SIG1*SIG2*((SIG1+SIG2)**2-1.0))
      U(I,J) = U(I,J)+XNU1*GGG
      V(I,J) = V(I,J)+XNU2*GGG
      W(I,J) = W(I,J)+XNU3*GGG
```

```
      GO TO 27
  260 W(I,J) = W(I,J)-GAMB(LPS)*FRB
   27 CONTINUE
      CALL FUSLGE(X(I,J),Y(I,J),Z(I,J),UF,VF,WF)
      U(I,J) = U(I,J)+XMCL+UF
      V(I,J) = V(I,J)+VF
      W(I,J) = W(I,J)-XMSL+WF
   28 CONTINUE
   29 CONTINUE
      IF(NTAPE.EQ.0) GO TO 30
      WRITE(4)PSI,XMU,XLAM,ALPHAT,NB,NRW,NA,NW
      WRITE(4) ((X(I,J),Y(I,J),Z(I,J),U(I,J),V(I,J),W(I,J),GAMA(I,J),
     1         A(I,J),I=1,NW1),J=1,NB1)
   30 IF(NCT.NE.0)GO TO 31
      IF(NXPT.NE.0)CALL VLCTY
      CALL OUTPUT
   31 NCT = NCT+1
      IF(NCT.GE.NPINT)NCT = 0
      PSI = PSI+DPSI
      NPS = NPS+1
      IF (NPS.GT.NA) NPS = 1
      IF(PSI.LE.PSIF) GO TO 32
      IF(NTAPE.NE.0) END FILE 4
      IF(NPNCH.EQ.0) GO TO 1
      PUNCH 1004
 1004 FORMAT(74HZZ     HELICOPTER WAKE VORTICITY CALCULATIONS  -  HARVEY
     1SELIB            ZZ )
      PUNCH 1001,((A(I,J),I=1,NW),J=1,NB)
      PUNCH 1003,((X(I,J),I=1,NW1),J=1,NB)
      PUNCH 1003,((Y(I,J),I=1,NW1),J=1,NB)
      PUNCH 1003,((Z(I,J),I=1,NW1),J=1,NB)
      GO TO 1
   32 DO 35  J=1,NB1
      TX1 = X(1,J)
      TY1 = Y(1,J)
      TZ1 = Z(1,J)
      DO 33 I=2,NW1
      TX2 = TX1
      TY2 = TY1
      TZ2 = TZ1
      TX1 = X(I,J)
      TY1 = Y(I,J)
      TZ1 = Z(I,J)
      X(I,J) = TX2+XLAM*U(I-1,J)*DPSI
      Y(I,J) = TY2+XLAM*V(I-1,J)*DPSI
      Z(I,J) = TZ2+XLAM*W(I-1,J)*DPSI
   33 CONTINUE
      XJ = FLOAT(J-1)*TPNB
      X(1,J) = COS(PSI+XJ)
      Y(1,J) = SIN(PSI+XJ)
      Z(1,J) = 0.0
   35 CONTINUE
      DO 38  J=1,NB1
      JPS = MOD(NPS+(NA*(J-1))/NB+NAB,NA)
      IF(JPS.EQ.0) JPS = NA
      JPS1 = JPS-1
```

```
      IF(JPS1.EQ.0)JPS1 = NA
      SEG1 = SEG(1,J)
      GAM1 = GAMA(1,J)
      TA1 = A(1,J)
   36 DO 37  I=2,NW
      GAM2 = GAM1
      GAM1 = GAMA(I,J)
      GAMA(I,J) = GAM2
      SEG2 = SEG1
      SEG1 = SEG(I,J)
      SEG(I,J) = SQRT((X(I,J)-X(I+1,J))**2+(Y(I,J)-Y(I+1,J))**2+(Z(I,J)-
     1           Z(I+1,J))**2)
      TA2 = TA1
      TA1 = A(I,J)
      A(I,J) = TA2*SQRT(SEG2/SEG(I,J))
   37 CONTINUE
      SEG(1,J) = SQRT((X(1,J)-X(2,J))**2+(Y(1,J)-Y(2,J))**2+(Z(1,J)-
     1           Z(2,J))**2)
      A(1,J) = A1(JPS)
      GAMA(1,J) = (GAMB(JPS)+GAMB(JPS1))/2.0
   38 CONTINUE
      GO TO 13
      END
```

```
$IBMAP ZZCLR    REF
*                               SUBROUTINE CLEAR
*                 SUBROUTINE TO SET FORTRAN LOCATIONS TO ZERO
*                 CALLING SEQUENCE - CALL CLEAR(X,Y)
*
        ENTRY    CLEAR
        BCI      1,CLEAR
 CLEAR  TRA      **
        SXA      SVE,1
        SXA      SVE+1,4
        LAC      CLEAR,4
        CLA      3,4
        SUB      2,4
        PAX      ,1
        TMI      ORDR               IN CASE LOC(Y) LESS THAN LOC(X)
        CLA      3,4
        STA      ZERO
        TRA      ZERO
 ORDR   CLA      2,4
        STA      ZERO
 ZERO   STZ      **,1
        TIX      ZERO,1,1
        STZ*     2,4
        STZ*     3,4
        LXA      SVE,1
        LXA      SVE+1,4
        TRA*     CLEAR
  SVE   BSS      2
        END
```

```
$IBFTC ZZIOT    LIST,REF
C      WAKE VORTICITY CALCULATION PROGRAM - SUBROUTINE IOOUT
       SUBROUTINE IOOUT
       COMMON X(340,4),Y(340,4),Z(340,4),U(340,4),V(340,4),W(340,4),
     1         GAMA(340,4),SEG(340,4),GAMB1(100),A1(100),A(340,4),PI,RAD,
     2         VMP,XMCL,XMSL,NB,NRW,NA,NW,NOPT,NTAPE,NPRINT,NDVCH,PSIO,
     3         XMU,XLAM,ALPHAT,PINT,PSIF,XNA,DPSI,NB1,NW1,XNW,XNB,TPNB,
     4         SAT,CAT,C1,C2,PSI,TPI,XI,T1,T2,XJ,NPS,JPS,IPS,IPS1,XXX,YYY,
     5         ZZZ,IST,INC,IFLG,SIG1,SIG2,SIG3,GGG,DEN,XNU1,XNU2,XNU3,IR1,
     6         XMX,XMY,XMZ,SIG4,SIG5,RR,SQI1,SF,SQI,SG,BF,LPS,SEG1,SEG2,
     7         SUM,LNCT,XIPT(400),YIPT(400),ZIPT(400),VX(400),VY(400),
     8         VZ(400),VXF(400),VYF(400),VZF(400),NXPT,NAB,FACTR,RB
       COMMON /FUSE/ XBAR(100),YBAR(100),ZBAR(100),SIGX(100),SIGZ(100),
     1         XI1(100),XI2(100),XI3(100),XI4(100),ETA1(100),ETA2(100),
     2         ETA3(100),ETA4(100),XLE(100),XME(100),XNE(100),XLZ(100),
     3         XXZ(100),XNZ(100),NFPT,RJ(4),EJ(4),HJ(4),EMJ(4),D1(100),
     4         D2(100),D3(100),D4(100),VXINF,VYINF,VZINF,UF,VF,WF
     1 WRITE(6,1000)NB,NRW,NA,NFPT,PSIO,PSIF,XLAM,XMU,ALPHAT,RB,FACTR
 1000 FORMAT(1H1,49X33HHELICOPTER WAKE VORTICITY PROGRAM //45X31HNUMBER
     1OF BLADES                 =I11 /45X31HNUMBER OF REVOLUTIONS OF WAKE =
     2 I11 /45X31HNUMBER OF AZIMUTH STATIONS     =I11/45X31HNUMBER OF FUS
     XELAGE POINTS        =I11/45X23HPSI (INITIAL)            =
     3           F11.3,8H DEGREES /45X23HPSI (FINAL)            =F11.3,
     4 8H DEGREES /45X23HLAMBDA                   =E12.5 /45X23HMU
     5             =E12.5 /45X23HALPHAT                  =F11.3,8H DEGREES /
     6         45X23HR/B                   =F11.3/45X23HVZ INFINITY FACTO
     7R     =F11.3)
     2 DPS = 360.0/FLOAT(NA)
       PS = 0.0
       WRITE(6,1001)
 1001 FORMAT(//30X3HPSI,15X22H  STRENGTH OF BLADE 1 ,14X20HCORE SIZE AT
     1BLADE 1 )
     3 DO 4  I=1,NA
       WRITE(6,1002)PS,GAMB1(I),A1(I)
 1002 FORMAT(F35.3,E30.5,E35.5)
       PS = PS+DPS
     4 CONTINUE
       RETURN
       END
```

```
$IBFTC ZZOUTP  LIST,REF
C     WAKE VORTICITY CALCULATION PROGRAM - SUBROUTINE OUTPUT
      SUBROUTINE OUTPUT
      COMMON X(340,4),Y(340,4),Z(340,4),U(340,4),V(340,4),W(340,4),
     1       GAMA(340,4),SEG(340,4),GAMB1(100),A1(100),A(340,4),PI,RAD,
     2        VMP,XMCL,XMSL,NB,NRW,NA,NW,NOPT,NTAPE,NPRINT,NDVCH,PSIO,
     3        XMU,XLAM,ALPHAT,PINT,PSIF,XNA,DPSI,NB1,NW1,XNW,XNB,TPNB,
     4        SAT,CAT,C1,C2,PSI,TPI,XI,T1,T2,XJ,NPS,JPS,IPS,IPS1,XXX,YYY,
     5        ZZZ,IST,IND,IFLG,SIG1,SIG2,SIG3,GGG,DEN,XNU1,XNU2,XNU3,IR1,
     6        XMX,XMY,XMZ,SIG4,SIG5,RR,SQI1,SF,SQI,SG,BF,LPS,SEG1,SEG2,
     7        SUM,LNCT,XIPT(400),YIPT(400),ZIPT(400),VX(400),VY(400),
     8        VZ(400),VXF(400),VYF(400),VZF(400),NXPT,NAB,FACTR,RB
    1 ILINE = 0
      PSID = PSI/RAD
      DPSID = DPSI/RAD
    2 DO 5 J=1,NB1
      IF(ILINE.EQ.0) WRITE(6,1000)NB,NA,NRW,XLAM,XMU,ALPHAT,DPSID,PSID
 1000 FORMAT(1H1,46X38HHELICOPTER WAKE VORTICITY DISTRIBUTION //13X
     1         15HNO. OF BLADES = I2,23X25HNO. OF AZIMUTH STATIONS = I3,
     2        21X21HNO. OF REV. OF WAKE = I2 /9X8HLAMBDA =E12.5,15X4HMU =
     3       E12.5,12X9HALPHA T = F7.3,5H DEG. 11X11HDELTA PSI = F7.3,
     4      5H DEG. //55X5HPSI = F8.3,8H DEGREES )
    3 WRITE(6,1002)J
 1002 FORMAT( /59X12HBLADE NUMBER I2 / )
    4 WRITE(6,1003)(I,X(I,J),Y(I,J),Z(I,J),U(I,J),V(I,J),W(I,J),
     1             GAMA(I,J),A(I,J),I=1,NW1,NPRINT)
 1003 FORMAT( 4X5HSTAT.,10X1HX,14X1HY,14X1HZ,14X2HVX,13X2HVY,13X2HVZ,
     1        10X8HSTRENGTH, 6X9HCORE SIZE /(I8,E18.5,7E15.5) )
      ILINE = ILINE + NW1/MAX0(NPRINT,1)+3
      IF (ILINE.GE.LNCT) ILINE = 0
    5 CONTINUE
      IF(NXPT.EQ.0) GO TO 6
      IF(ILINE.EQ.0)WRITE(6,1000)NB,NA,NRW,XLAM,XMU,ALPHAT,DPSID,PSID
      WRITE(6,1004)(XIPT(I),YIPT(I),ZIPT(I),VX(I),VY(I),VZ(I),I=1,NXPT)
 1004 FORMAT( /53X26HVELOCITIES AT OTHER POINTS //19X1HX,14X1HY,14X1HZ,
     1        14X2HVX,13X2HVY,13X2HVZ /(E26.5,5E15.5 ) )
    6 RETURN
      END
```

```
$IBFTC ZZFSLG  LIST,REF
C      WAKE VORTICITY CALCULATION PROGRAM - SUBROUTINE FUSLGE
       SUBROUTINE FUSLGE(XD,YD,ZD,UFD,VFD,WFD)
       COMMON /FUSE/ XBAR(100),YBAR(100),ZBAR(100),SIGX(100),SIGZ(100),
     1         XI1(100),XI2(100),XI3(100),XI4(100),ETA1(100),ETA2(100),
     2         ETA3(100),ETA4(100),XLE(100),XME(100),XNE(100),XLZ(100),
     3         XMZ(100),XNZ(100),NFPT,RJ(4),EJ(4),HJ(4),EMJ(4),D1(100),
     4         D2(100),D3(100),D4(100),VXINF,VYINF,VZINF,UF,VF,WF
       DIMENSION XIK(100,4),ETAK(100,4),DDJ(100,4)
       EQUIVALENCE (XIK,XI1),(ETAK,ETA1),(DDJ,D1)
     1 SUMU = 0.0
       SUMV = 0.0
       SUMW = 0.0
       IF(NFPT.EQ.0) GO TO 13
     2 DO 12  J=1,NFPT
       NFLG = 1
       XLX = XME(J)*XNZ(J)-XMZ(J)*XNE(J)
       XMX = XNE(J)*XLZ(J)-XNZ(J)*XLE(J)
       XNX = XLE(J)*XMZ(J)-XLZ(J)*XME(J)
       XB = XD-XBAR(J)
       YB = YD-YBAR(J)
       ZB = ZD-ZBAR(J)
       D5 = (XI3(J)-XI1(J))**2+(ETA3(J)-ETA1(J))**2
       D6 = (XI4(J)-XI2(J))**2+(ETA4(J)-ETA2(J))**2
       D7 = AMAX1(D5,D6)
     3 XI = XLX*XB+XMX*YB+XNX*ZB
       ETA = XLE(J)*XB+XME(J)*YB+XNE(J)*ZB
       ZETA = XLZ(J)*XB+XMZ(J)*YB+XNZ(J)*ZB
       RO = XI**2+ETA**2+ZETA**2
       TJ = RO/D7
       IF(TJ.LT.6.0) GO TO 5
     4 SJ = .5*(XI3(J)-XI1(J))*(ETA2(J)-ETA4(J))/(RO*SQRT(RO))
       VXI = SJ*XI
       VETA = SJ*ETA
       VZETA = SJ*ZETA
       GO TO 90
     5 DO 6  I=1,4
       RJ(I) = SQRT((XI-XIK(J,I))**2+(ETA-ETAK(J,I))**2+ZETA**2)
       EJ(I) = ZETA**2+(XI-XIK(J,I))**2
       HJ(I) = (ETA-ETAK(J,I))*(XI-XIK(J,I))
       I1 = I+1
       IF(I.EQ.4) I1 = 1
       TRM1 = XIK(J,I1)-XIK(J,I)
       IF(TRM1.EQ.0.0) TRM1 = 1.0E-6
       EMJ(I) = (ETAK(J,I1)-ETAK(J,I))/TRM1
     6 CONTINUE
       VXI = 0.0
       VETA = 0.0
       VZETA = 0.0
     7 DO 9  I=1,4
       I1 = I+1
       IF(I.EQ.4) I1 = 1
       TRM1 = (RJ(I)+RJ(I1)-DDJ(J,I))/(RJ(I)+RJ(I1)+DDJ(J,I))
       TRM1 = ALOG(TRM1)
       TRM2 = (ETAK(J,I1)-ETAK(J,I))/DDJ(J,I)
       TRM3 = (XIK(J,I)-XIK(J,I1))/DDJ(J,I)
```

```
      VXI = VXI+TRM2*TRM1
      VETA = VETA+TRM3*TRM1
    8 IF(ZETA.EQ.0.0) GO TO 9
      TRM4 = ATAN((EMJ(I)*EJ(I)-HJ(I))/(ZETA*RJ(I)))
      TRM5 = ATAN((EMJ(I)*EJ(I1)-HJ(I1))/(ZETA*RJ(I1)))
      VZETA = VZETA+TRM4-TRM5
    9 CONTINUE
   90 VVX = XLX*VXI+XLE(J)*VETA+XLZ(J)*VZETA
      VVY = XMX*VXI+XME(J)*VETA+XMZ(J)*VZETA
      VVZ = XNX*VXI+XNE(J)*VETA+XNZ(J)*VZETA
      GO TO (10,11),NFLG
   10 VVVX = VVX
      VVVY = VVY
      VVVZ = VVZ
      YB = -YD-YBAR(J)
      NFLG = 2
      GO TO 3
   11 TRM = SIGX(J)*VXINF+SIGZ(J)*VZINF
      SUMU = SUMU+TRM*(VVVX+VVX)
      SUMV = SUMV+TRM*(VVVY-VVY)
      SUMW = SUMW+TRM*(VVVZ+VVZ)
   12 CONTINUE
   13 UFD = SUMU
      VFD = SUMV
      WFD = SUMW
      RETURN
      END
```

```
$IBFTC ZZVLCT  LIST,REF
C      WAKE VORTICITY CALCULATION PROGRAM - SUBROUTINE VLCTY
       SUBROUTINE VLCTY
       COMMON X(340,4),Y(340,4),Z(340,4),U(340,4),V(340,4),W(340,4),
      1      GAMA(340,4),SEG(340,4),GAMB1(100),A1(100),A(340,4),PI,RAD,
      2       VMP,XMCL,XMSL,NB,NRW,NA,NW,NOPT,NTAPE,NPRINT,NDVCH,PSIC,
      3       XMU,XLAM,ALPHAT,PINT,PSIF,XNA,DPSI,NB1,NW1,XNW,XNB,TPNB,
      4       SAT,CAT,C1,C2,PSI,TPI,X1,T1,T2,XJ,NPS,JPS,IPS,IPS1,XXX,YYY,
      5       ZZZ,IST,IND,IFLG,SIG1,SIG2,SIG3,GGG,DEN,XNU1,XNU2,XNU3,IR1,
      6       XMX,XMY,XMZ,SIG4,SIG5,RR,SQI1,SF,SQI,SG,BF,LPS,SEG1,SEG2,
      7       SUM,LNCT,XIPT(400),YIPT(400),ZIPT(400),VX(400),VY(400),
      8       VZ(400),VXF(400),VYF(400),VZF(400),NXPT,NAB,FACTR,RB
     1 DO 7  I=1,NXPT
       VX(I) = 0.0
       VY(I) = 0.0
       VZ(I) = 0.0
     2 DO 5  J=1,NB1
       SIG2 = SQRT((XIPT(I)-X(1,J))**2+(YIPT(I)-Y(1,J))**2+(ZIPT(I)-
      1      Z(1,J))**2)
     3 DO 4  K=1,NW
       SIG1 = SIG2
       SIG2 = SQRT((XIPT(I)-X(K+1,J))**2+(YIPT(I)-Y(K+1,J))**2+(ZIPT(I)-
      1      Z(K+1,J))**2)
       SEGSQ = SEG(K,J)**2
       HM1 = SIG1**2+SIG2**2
       IF(HM1.GT.SEGSQ)GO TO 30
       HM2 = .25*((SIG1+SIG2)**2-SEGSQ)*(SEGSQ-(SIG1-SIG2)**2)/SEGSQ
       IF(HM2.GT.A(K,J)**2)GO TO 30
       GGG = GAMA(K,J)/SEG(K,J)
       GO TO 31
    30 GGG = GAMA(K,J)*(SIG1+SIG2)/(SIG1*SIG2*((SIG1+SIG2)**2-SEGSQ))
    31 XNU1 = (YIPT(I)-Y(K,J))*(Z(K,J)-Z(K+1,J))-(ZIPT(I)-Z(K,J))*
      1       (Y(K,J)-Y(K+1,J))
       XNU2 = (ZIPT(I)-Z(K,J))*(X(K,J)-X(K+1,J))-(XIPT(I)-X(K,J))*
      1       (Z(K,J)-Z(K+1,J))
       XNU3 = (XIPT(I)-X(K,J))*(Y(K,J)-Y(K+1,J))-(YIPT(I)-Y(K,J))*
      1       (X(K,J)-X(K+1,J))
       VX(I) = VX(I)+XNU1*GGG
       VY(I) = VY(I)+XNU2*GGG
       VZ(I) = VZ(I)+XNU3*GGG
     4 CONTINUE
     5 CONTINUE
       SIG1 = SQRT(XIPT(I)**2+YIPT(I)**2+ZIPT(I)**2)
       DO 6  L=1,NB
       LPS = MOD(NPS+(NA*(L-1))/NB+NAB,NA)
       IF(LPS.EQ.0) LPS = NA
       XNU1 = -YIPT(I)*Z(1,L)+ZIPT(I)*Y(1,L)
       XNU2 = -ZIPT(I)*X(1,L)+XIPT(I)*Z(1,L)
       XNU3 = -XIPT(I)*Y(1,L)+YIPT(I)*X(1,L)
       SIG2 = SQRT((XIPT(I)-X(1,L))**2+(YIPT(I)-Y(1,L))**2+(ZIPT(I)-
      1      Z(1,L))**2)
       DEN = SIG1*SIG2*((SIG1+SIG2)**2-1.0)
       IF(DEN.EQ.0.0) DEN = .001
       GGG = GAMB1(LPS)*(SIG1+SIG2)/DEN
       VX(I) = VX(I)+XNU1*GGG
       VY(I) = VY(I)+XNU2*GGG
```

```
      VZ(I) = VZ(I)+XNU3*GGG
    6 CONTINUE
      VX(I) = VX(I)+XMCL+VXF(I)
      VY(I) = VY(I)+VYF(I)
      VZ(I) = VZ(I)-XMSL+VZF(I)
    7 CONTINUE
      RETURN
      END
```

APPENDIX II

OPERATIONAL INFORMATION FOR THE SUPPLEMENTAL FUSELAGE PROGRAM

This program is written completely in FORTRAN IV.

INPUTS

CARD 1	NPTS:	Number of fuselage elements N_f
	NPRNT:	Number of B_{ij} coefficients to be printed; i. e., NPRNT = (NPTS)(NPTS).
	EPS:	Desired accuracy in iterative solution of equations; i. e., if EPS = .001, the solution will be obtained to within $\pm$ 0.1% of the exact result.
	NIT:	Maximum number of iterations to be allowed in solving the equations (in case of divergence of the iterations).
	NDUCH:	Not used.
CARD 2, 3, ...,	(2)(NPTS) + 1	x_{11}, y_{11}, z_{11} ; x_{21}, y_{21}, z_{21}. x_{31}, y_{31}, z_{31} ; x_{41}, y_{41}, z_{41}. x_{12}, y_{12}, z_{12} ; x_{22}, y_{22}, z_{22}. etc.

A listing of the program is given on the pages which follow.

```
$IBFTC ZZHFPF  LIST,REF
C     CALCULATION OF POTENTIAL FLOW ABOUT A HELICOPTER FUSELAGE
      COMMON X1(100),X2(100),X3(100),X4(100),Y1(100),Y2(100),Y3(100),
     1       Y4(100),Z1(100),Z2(100),Z3(100),Z4(100),XBAR(100),YBAR(100)
     2       ,ZBAR(100),AMTX(3,4),XPT(4),YPT(4),ZPT(4),XI1(100),XI2(100)
     3       ,XI3(100),XI4(100),ETA1(100),ETA2(100),ETA3(100),ETA4(100),
     4       ZETA1(100),ZETA2(100),ZETA3(100),ZETA4(100),XLX(100),
     5       XMX(100),XNX(100),XLE(100),XME(100),XNE(100),XLZ(100),
     6       XMZ(100),XNZ(100),RIJ(4),EIJ(4),HIJ(4),D1(100),D2(100),
     7       D3(100),D4(100),B(100,100),SIGX(100),SIGZ(100),NPTS,NOVCH,
     8       EPS,AN,BN,GN,AX,BX,GX,AE,BE,GE,CX,CE,CZ,D5,D6,D7,SJ,NFLG,
     9       EM1,EM2,EM3,EM4,XPP,YPP,ZPP,YRPP,XIIJ,ETAIJ,ZETAIJ,RO,RI
      COMMON XIRIJ,ETARIJ,ZETRIJ,TIJ,TRIJ,VXI,VETA,VZETA,TMP1,TMP2,TMP3,
     1       TMP4,TMP,VX,VY,VZ,AIJ,ARIJ,N1,N2,NPRNT,MPRNT,NIT
      DIMENSION X(100,4),Y(100,4),Z(100,4),XIK(100,4),ETAK(100,4),
     1          ZETAK(100,4)
      EQUIVALENCE (X,X1),(Y,Y1),(Z,Z1),(XIK,XI1),(ETAK,ETA1),(ZETAK,
     1             ZETA1)
    1 READ 1000,NPTS,NPRNT,EPS,NIT,NOVCH
 1000 FORMAT(2I6,F6.0,2I6)
      READ 1001,((X(I,J),Y(I,J),Z(I,J),J=1,4),I=1,NPTS)
 1001 FORMAT(6F12.5)
    2 DO 18  I=1,NPTS
      AN = (Y4(I)-Y2(I))*(Z3(I)-Z1(I))-(Z4(I)-Z2(I))*(Y3(I)-Y1(I))
      BN = (Z4(I)-Z2(I))*(X3(I)-X1(I))-(X4(I)-X2(I))*(Z3(I)-Z1(I))
      GN = (X4(I)-X2(I))*(Y3(I)-Y1(I))-(Y4(I)-Y2(I))*(X3(I)-X1(I))
      XBAR(I) = (X1(I)+X2(I)+X3(I)+X4(I))/4.0
      YBAR(I) = (Y1(I)+Y2(I)+Y3(I)+Y4(I))/4.0
      ZBAR(I) = (Z1(I)+Z2(I)+Z3(I)+Z4(I))/4.0
    3 IF(AN.NE.0.0) GO TO 8
      IF(BN.NE.0.0) GO TO 8
      IF(GN.NE.0.0) GO TO 6
    4 WRITE(6,1002)I,(X(I,J),Y(I,J),Z(I,J),J=1,4)
 1002 FORMAT(40H BAD SET OF POINTS FOR QUADRILATERAL NO. I5/4(3F9.4,5X))
      GO TO 1
    6 DO 7  J=1,4
      XPT(J) = X(I,J)-XBAR(I)
      YPT(J) = Y(I,J)-YBAR(I)
      ZPT(J) = 0.0
    7 CONTINUE
      GO TO 14
    8 AMTX(1,1) = AN
      AMTX(1,2) = BN
      AMTX(1,3) = GN
      AMTX(2,1) = BN
      AMTX(2,2) = -AN
      AMTX(2,3) = 0.0
      IF(AN.NE.0.0) GO TO 11
    9 AMTX(3,1) = 0.0
      AMTX(3,2) = GN
      AMTX(3,3) = -BN
      DO 10  J=1,4
      AMTX(1,4) = BN*YBAR(I)+GN*ZBAR(I)
      AMTX(2,4) = BN*X(I,J)
      AMTX(3,4) = GN*Y(I,J)-BN*Z(I,J)
      CALL SIMSOL (AMTX,3,3)
```

```
      XPT(J) = AMTX(1,4)-XBAR(I)
      YPT(J) = AMTX(2,4)-YBAR(I)
      ZPT(J) = AMTX(3,4)-ZBAR(I)
   10 CONTINUE
      GO TO 14
   11 AMTX(3,1) = GN
      AMTX(3,2) = 0.0
      AMTX(3,3) = -AN
   12 DO 13  J=1,4
      AMTX(1,4) = AN*XBAR(I)+BN*YBAR(I)+GN*ZBAR(I)
      AMTX(2,4) = BN*X(I,J)-AN*Y(I,J)
      AMTX(3,4) = GN*X(I,J)-AN*Z(I,J)
      CALL SIMSCL(AMTX,3,3)
      XPT(J) = AMTX(1,4)-XBAR(I)
      YPT(J) = AMTX(2,4)-YBAR(I)
      ZPT(J) = AMTX(3,4)-ZBAR(I)
   13 CONTINUE
   14 AX = XPT(3)-XPT(1)
      BX = YPT(3)-YPT(1)
      GX = ZPT(3)-ZPT(1)
      AE = BN*GX-BX*GN
      BE = GN*AX-GX*AN
      GE = AN*BX-AX*BN
      CX = 1.0/SQRT(AX**2+BX**2+GX**2)
      CE = 1.0/SQRT(AE**2+BE**2+GE**2)
      CZ = 1.0/SQRT(AN**2+BN**2+GN**2)
      XLX(I) = CX*AX
      XMX(I) = CX*BX
      XNX(I) = CX*GX
      XLE(I) = CE*AE
      XME(I) = CE*BE
      XNE(I) = CE*GE
      XLZ(I) = CZ*AN
      XMZ(I) = CZ*BN
      XNZ(I) = CZ*GN
   16 DO 17  J=1,4
      XIK(I,J) = XLX(I)*XPT(J)+XMX(I)*YPT(J)+XNX(I)*ZPT(J)
      ETAK(I,J) = XLE(I)*XPT(J)+XME(I)*YPT(J)+XNE(I)*ZPT(J)
      ZETAK(I,J) = XLZ(I)*XPT(J)+XMZ(I)*YPT(J)+XNZ(I)*ZPT(J)
   17 CONTINUE
   18 CONTINUE
   19 DO 31  J=1,NPTS
      D1(J) = SQRT((XI2(J)-XI1(J))**2+(ETA2(J)-ETA1(J))**2)
      D2(J) = SQRT((XI3(J)-XI2(J))**2+(ETA3(J)-ETA2(J))**2)
      D3(J) = SQRT((XI4(J)-XI3(J))**2+(ETA4(J)-ETA3(J))**2)
      D4(J) = SQRT((XI1(J)-XI4(J))**2+(ETA1(J)-ETA4(J))**2)
      D5 = (XI3(J)-XI1(J))**2+(ETA3(J)-ETA1(J))**2
      D6 = (XI4(J)-XI2(J))**2+(ETA4(J)-ETA2(J))**2
      D7 = AMAX1(D5,D6)
      SJ = .5*(XI3(J)-XI1(J))*(ETA2(J)-ETA4(J))
      TRM = XI2(J)-XI1(J)
      IF(TRM.EQ.0.0)TRM = 1.0E-6
      EM1 = (ETA2(J)-ETA1(J))/TRM
      TRM = XI3(J)-XI2(J)
      IF(TRM.EQ.0.0)TRM = 1.0E-6
      EM2 = (ETA3(J)-ETA2(J))/TRM
```

```
      TRM = XI4(J)-XI3(J)
      IF(TRM.EQ.0.0)TRM = 1.0E-6
      EM3 = (ETA4(J)-ETA3(J))/TRM
      TRM = XI1(J)-XI4(J)
      IF(TRM.EQ.0.0)TRM = 1.0E-6
      EM4 = (ETA1(J)-ETA4(J))/TRM
   20 DO 30  I=1,NPTS
      NFLG = 1
      XPP = XBAR(I)-XBAR(J)
      YPP = YBAR(I)-YBAR(J)
      ZPP = ZBAR(I)-ZBAR(J)
      YRPP = -YBAR(I)-YBAR(J)
      XIIJ = XLX(J)*XPP+XMX(J)*YPP+XNX(J)*ZPP
      ETAIJ = XLE(J)*XPP+XME(J)*YPP+XNE(J)*ZPP
      ZETAIJ = XLZ(J)*XPP+XMZ(J)*YPP+XNZ(J)*ZPP
      XIRIJ = XLX(J)*XPP+XMX(J)*YRPP+XNX(J)*ZPP
      ETARIJ = XLE(J)*XPP+XME(J)*YRPP+XNE(J)*ZPP
      ZETRIJ = XLZ(J)*XPP+XMZ(J)*YRPP+XNZ(J)*ZPP
      R1 = XIRIJ**2+ETARIJ**2+ZETRIJ**2
      R0 = XIIJ**2+ETAIJ**2+ZETAIJ**2
      TIJ = R0/C7
      TRIJ = R1/C7
   21 IF(I.NE.J) GO TO 22
      VXI = 0.0
      VETA = 0.0
      VZETA = 6.2831853072
      GO TO 27
   22 IF(TIJ.GT.6.0) GO TO 26
   23 DO 24  K=1,4
      RIJ(K) = SQRT((XIIJ-XIK(J,K))**2+(ETAIJ-ETAK(J,K))**2+ZETAIJ**2)
      EIJ(K) = ZETAIJ**2+(XIIJ-XIK(J,K))**2
      HIJ(K) = (ETAIJ-ETAK(J,K))*(XIIJ-XIK(J,K))
   24 CONTINUE
      TMP1 = ALOG((RIJ(1)+RIJ(2)-D1(J))/(RIJ(1)+RIJ(2)+D1(J)))/D1(J)
      TMP2 = ALOG((RIJ(2)+RIJ(3)-D2(J))/(RIJ(2)+RIJ(3)+D2(J)))/D2(J)
      TMP3 = ALOG((RIJ(3)+RIJ(4)-D3(J))/(RIJ(3)+RIJ(4)+D3(J)))/D3(J)
      TMP4 = ALOG((RIJ(4)+RIJ(1)-D4(J))/(RIJ(4)+RIJ(1)+D4(J)))/D4(J)
      VXI = (ETA1(J)-ETA2(J))*TMP1+(ETA2(J)-ETA3(J))*TMP2+(ETA3(J)-
     1       ETA4(J))*TMP3+(ETA4(J)-ETA1(J))*TMP4
      VXI = -VXI
      VETA = (XI1(J)-XI2(J))*TMP1+(XI2(J)-XI3(J))*TMP2+(XI3(J)-XI4(J))*
     1        TMP3+(XI4(J)-XI1(J))*TMP4
      IF(ZETAIJ.NE.0.0) GO TO 25
      VZETA = 0.0
      GO TO 27
   25 VZETA = ATAN((EM1*EIJ(1)-HIJ(1))/(ZETAIJ*RIJ(1)))-ATAN((EM1*EIJ(2)
     1        -HIJ(2))/(ZETAIJ*RIJ(2)))+ATAN((EM2*EIJ(2)-HIJ(2))/(ZETAIJ
     2        *RIJ(2)))-ATAN((EM2*EIJ(3)-HIJ(3))/(ZETAIJ*RIJ(3)))+
     3        ATAN((EM3*EIJ(3)-HIJ(3))/(ZETAIJ*RIJ(3)))-ATAN((EM3*EIJ(4)
     4        -HIJ(4))/(ZETAIJ*RIJ(4)))+ATAN((EM4*EIJ(4)-HIJ(4))/(ZETAIJ
     5        *RIJ(4)))-ATAN((EM4*EIJ(1)-HIJ(1))/(ZETAIJ*RIJ(1)))
      GO TO 27
   26 TMP = SJ/(R0*SQRT(R0))
      VXI = XIIJ*TMP
      VETA = ETAIJ*TMP
      VZETA = ZETAIJ*TMP
```

```
   27 VX = XLX(J)*VXI+XLE(J)*VETA+XLZ(J)*VZETA
      VY = XMX(J)*VXI+XME(J)*VETA+XMZ(J)*VZETA
      VZ = XNX(J)*VXI+XNE(J)*VETA+XNZ(J)*VZETA
      GO TO (28,29),NFLG
   28 AIJ = XLZ(I)*VX+XMZ(I)*VY+XNZ(I)*VZ
      NFLG = 2
      XIIJ = XIRIJ
      ETAIJ = ETARIJ
      ZETAIJ = ZETRIJ
      RO = R1
      TIJ = TRIJ
      GO TO 22
   29 ARIJ = XLZ(I)*VX-XMZ(I)*VY+XNZ(I)*VZ
      B(I,J) = AIJ+ARIJ
   30 CONTINUE
   31 CONTINUE
      N1 = NPTS+1
      N2 = NPTS+2
   32 DO 33  I=1,NPTS
      B(I,N1) = -XLZ(I)
      B(I,N2) = -XNZ(I)
   33 CONTINUE
      IF(NPRNT.EQ.0) GO TO 38
      MPRINT = MIN0(NPRNT,NPTS)
   34 DO 37  I=1,MPRINT,8
      I8 = MIN0(I+7,MPRINT)
      WRITE(6,1003)I,I8,MPRINT
 1003 FORMAT(1H1,44X42HPOTENTIAL FLOW ABOUT A HELICOPTER FUSELAGE //50X
     1          11HBIJ FOR J =I3,2H -I3,9H , I = 1-I3/)
   35 DO 36  J=1,MPRINT
      WRITE(6,1004)(B(J,K),K=I,I8)
 1004 FORMAT(8E16.5)
   36 CONTINUE
   37 CONTINUE
   38 CALL SIMEQ
      CALL OUTPUT
      GO TO 1
      END
```

```
$IBFTC ZZSMEQ  LIST,REF
C     CALCULATION OF POTENTIAL FLOW ABOUT A HELICOPTER FUSELAGE - SIMEQ
      SUBROUTINE SIMEQ
      COMMON X1(100),X2(100),X3(100),X4(100),Y1(100),Y2(100),Y3(100),
     1       Y4(100),Z1(100),Z2(100),Z3(100),Z4(100),XBAR(100),YBAR(100)
     2       ,ZBAR(100),AMTX(3,4),XPT(4),YPT(4),ZPT(4),XI1(100),XI2(100)
     3       ,XI3(100),XI4(100),ETA1(100),ETA2(100),ETA3(100),ETA4(100),
     4       ZETA1(100),ZETA2(100),ZETA3(100),ZETA4(100),XLX(100),
     5       XMX(100),XNX(100),XLE(100),XME(100),XNE(100),XLZ(100),
     6       XMZ(100),XNZ(100),RIJ(4),EIJ(4),HIJ(4),D1(100),D2(100),
     7       D3(100),D4(100),B(100,102),SIGX(100),SIGZ(100),NPTS,NOVCH,
     8       EPS,AN,BN,GN,AX,BX,GX,AE,BE,GE,CX,CE,CZ,C5,D6,D7,SJ,NFLG,
     9       EM1,EM2,EM3,EM4,XPP,YPP,ZPP,YRPP,XIIJ,ETAIJ,ZETAIJ,R0,R1
      COMMON XIRIJ,ETARIJ,ZETRIJ,TIJ,TRIJ,VXI,VETA,VZETA,TMP1,TMP2,TMP3,
     1       TMP4,TMP,VX,VY,VZ,AIJ,ARIJ,N1,N2,NPRNT,MPRNT,NIT
      DIMENSION X(100,4),Y(100,4),Z(100,4),XIK(100,4),ETAK(100,4),
     1          ZETAK(100,4)
      EQUIVALENCE (X,X1),(Y,Y1),(Z,Z1),(XIK,XI1),(ETAK,ETA1),(ZETAK,
     1            ZETA1)
      DIMENSION U1(100),U2(100)
    1 JS = N1
      EPS1 = 100.0*EPS
    2 IT = 0
    3 DO 6  I=1,NPTS
      U1(I) = 0.0
    4 DO 5  J=1,NPTS
      TERM = -B(I,J)/B(I,I)
      IF(I.EQ.J) TERM = 0.0
      U1(I) = U1(I)+TERM*U1(J)
    5 CONTINUE
      U1(I) = U1(I)+B(I,JS)/B(I,I)
    6 CONTINUE
    7 DO 10  I=1,NPTS
      IF(U2(I).NE.0.0)GO TO 8
      TMP = ABS(U2(I)-U1(I))
      GO TO 9
    8 TMP = ABS((U2(I)-U1(I))/U2(I))
    9 IF(TMP.GT.EPS) GO TO 15
   10 CONTINUE
      IF(JS.EQ.N2) GO TO 13
   11 DO 12  I=1,NPTS
      SIGX(I) = U1(I)
   12 CONTINUE
      JS = N2
      GO TO 2
   13 DO 14  I=1,NPTS
      SIGZ(I) = U1(I)
   14 CONTINUE
      RETURN
   15 IT = IT+1
      IF (IT.GE.NIT) GO TO 18
   16 DO 17  I=1,NPTS
      U2(I) = U1(I)
   17 CONTINUE
      GO TO 3
   18 IF(JS.EQ.N2) GO TO 19
```

```
      WRITE(6,1CCC) EPS1,NIT
 1000 FCRMAT (5X48HEQUATICNS FCR SIGMA X DID NCT CCNVERGE TC WITHIN F7.4
     1        ,12H PER CENT IN I6,11H ITERATICNS )
      GC TO 11
   19 WRITE(6,1CC1) EPS1,NIT
 1001 FCRMAT( 5X48HEQUATICNS FCR SIGMA Z DID NCT CCNVERGE TO WITHIN F7.4
     1        ,12H PERCENT IN I6,11H ITERATICNS )
      GC TO 13
      END
```

```
$IBFTC ZZOUT    LIST,REF
C     CALCULATION OF POTENTIAL FLOW ABOUT A HELICOPTER FUSELAGE - OUTPUT
      SUBROUTINE OUTPUT
      COMMON X1(100),X2(100),X3(100),X4(100),Y1(100),Y2(100),Y3(100),
     1       Y4(100),Z1(100),Z2(100),Z3(100),Z4(100),XBAR(100),YBAR(100)
     2       ,ZBAR(100),AMTX(3,4),XPT(4),YPT(4),ZPT(4),XI1(100),XI2(100)
     3       ,XI3(100),XI4(100),ETA1(100),ETA2(100),ETA3(100),ETA4(100),
     4       ZETA1(100),ZETA2(100),ZETA3(100),ZETA4(100),XLX(100),
     5       XMX(100),XNX(100),XLE(100),XME(100),XNE(100),XLZ(100),
     6       XMZ(100),XNZ(100),RIJ(4),EIJ(4),HIJ(4),D1(100),D2(100),
     7       D3(100),D4(100),B(100,102),SIGX(100),SIGZ(100),NPTS,NOVCH,
     8       EPS,AN,BN,GN,AX,BX,GX,AE,BE,GE,CX,CE,CZ,C5,C6,D7,SJ,NFLG,
     9       EM1,EM2,EM3,EM4,XPP,YPP,ZPP,YRPP,XIIJ,ETAIJ,ZETAIJ,R0,R1
      COMMON XIRIJ,ETARIJ,ZETRIJ,TIJ,TRIJ,VXI,VETA,VZETA,TMP1,TMP2,TMP3,
     1       TMP4,TMP,VX,VY,VZ,AIJ,ARIJ,N1,N2,NPRNT,MPRNT,NIT
      DIMENSION X(100,4),Y(100,4),Z(100,4),XIK(100,4),ETAK(100,4),
     1          ZETAK(100,4)
      EQUIVALENCE (X,X1),(Y,Y1),(Z,Z1),(XIK,XI1),(ETAK,ETA1),(ZETAK,
     1             ZETA1)
    1 PUNCH 1000,NPTS
 1000 FORMAT(32HZZ   HELICOPTER FUSELAGE PROGRAM I6,22H POINTS - HARVEY
     1SELIB,12X2HZZ )
      I1 = 1
      I2 = 2
      I3 = 3
      I4 = 4
    2 DO 3  I=1,NPTS
      PUNCH 1001, XBAR(I),YBAR(I),ZBAR(I),SIGX(I),SIGZ(I),ZERO,I,I1
      PUNCH 1001,XI1(I),XI2(I),XI3(I),XI4(I),ETA1(I),ETA2(I),I,I2
      PUNCH 1001,ETA3(I),ETA4(I),D1(I),D2(I),D3(I),D4(I),I,I3
      PUNCH 1001,XLE(I),XME(I),XNE(I),XLZ(I),XMZ(I),XNZ(I),I,I4
 1001 FORMAT(6E12.5,I6,I2)
    3 CONTINUE
      NPAGE = NPTS/50
      IF(NPAGE*50.LT.NPTS)NPAGE = NPAGE+1
    4 DO 5  I=1,NPAGE
      I1 = 50*(I-1)+1
      I2 = MIN0(I1+49,NPTS)
      WRITE(6,1002)(SIGX(J),SIGZ(J),XLZ(J),XMZ(J),XNZ(J),J=I1,I2)
 1002 FORMAT(1H1,44X42HPOTENTIAL FLOW ABOUT A HELICOPTER FUSELAGE //18X
     1       7HSIGMA X,15X7HSIGMA Z,12X11HLAMBDA ZETA, 14X7HMU ZETA,15X
     2       7HNU ZETA / (E27.5,4E22.5) )
    5 CONTINUE
      RETURN
      END
```

```
$IBFTC GBSIMS
      SUBROUTINE SIMSOL(A,KK,LL)                                         C19  001
      DIMENSION  A(LL,LL)
C  KK- SIZE TO SOLVE  , LL  1ST  DIMENSION OF A IN MAIN PROGRAM          C19  003
      N=KK                                                               C19  004
      L=1                                                                C19  005
      N1=N+1                                                             C19  006
   10 L1=L+1                                                             C19  007
      IF(L-N)21,21,50                                                    C19  008
   21 K=0                                                                C19  009
      BIG=0.0
      DO 25 I=L,N                                                        C19  010
      Z=ABS(A(I,L))
      IF (Z.LE.BIG) GO TO 25
      K=I
      BIG=Z
   25 CONTINUE                                                           C19  014
   26 IF (BIG.LE.0.0) CALL DUMP
C     DETERMINANT= 0 ,NO SOLUTION                                        C19  016
   32 IF(K-L)26,40,35                                                    C19  017
   35 DO 37 J=L,N1                                                       C19  018
      B=A(K,J)                                                           C19  019
      A(K,J)=A(L,J)                                                      C19  020
      A(L,J)=B                                                           C19  021
   37 CONTINUE                                                           C19  022
   40 DO 41 J=L1,N1                                                      C19  023
   41 A(L,J)= A(L,J)/A(L,L)                                              C19  024
   42 A(L,L)= 1.                                                         C19  025
      IF(L-N)43,50,26                                                    C19  026
   43 DO 48 I=L1,N                                                       C19  027
      IF(A(I,L))44,48,44                                                 C19  028
   44 DO 45 J=L1,N1                                                      C19  029
   45 A(I,J)= A(I,J)- A(L,J)*A(I,L)                                      C19  030
   48 CONTINUE                                                           C19  031
      L=L1                                                               C19  032
      GO TO 10                                                           C19  033
   50 N2=N-1                                                             C19  034
      IF(N2)51,61,51                                                     C19  035
   51  DO 60 I2=1,N2                                                     C19  036
      I=N-I2                                                             C19  037
      I1=I+1                                                             C19  038
      DO 59 J=I1,N                                                       C19  039
      IF(A(I,J))58,59,58                                                 C19  040
   58 A(I,N1)= A(I,N1)-A(I,J)*A(J,N1)                                    C19  041
   59 CONTINUE                                                           C19  042
   60 CONTINUE                                                           C19  043
   61 RETURN                                                             C19  044
      END
```

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Cornell Aeronautical Laboratory, Inc. Buffalo, New York 14221	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

Theoretical Prediction of the Flow in the Wake of a Helicopter Rotor
Part 2 - Formulation and Application of the Rotor Wake-Flow Computer Program

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report - Part 2 , September 1964-September 1965

5. AUTHOR(S) (Last name, first name, initial)

Crimi, Peter

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1965	75	8

8a. CONTRACT OR GRANT NO. DA 30-069-AMC-645(R) b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) BB-1994-S-2 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. AVAILABILITY/LIMITATION NOTICES

11. SUPPLEMENTARY NOTES Part 1 of this report (BB-1994-S-1) discusses the problem formulation and the computational results.	12. SPONSORING MILITARY ACTIVITY U. S. Army Ballistic Research Laboratories Aberdeen Proving Ground, Maryland

13. ABSTRACT

This report describes two digital computer programs which direct the calculation of the time-varying flow in the vicinity of a helicopter rotor in forward or hovering flight. Fuselage interference effects are taken into account. The applicability of these programs to specific problems and procedures for their use are the subjects treated here.

First, the assumptions made in constructing the mathematical model and the relationship of the model to the physical flow are outlined. In this connection, the assumptions necessary for numerical analysis and the functional structure of the programs are also given.

Then, the formulations which were coded are presented. Included in the formulations are the coordinate identifications used and the definitions of program variables.

Finally, the procedures for 'mplementation of the programs are given. The relationship of input quantities to aircraft flight parameters, program accuracy and computer running time are specified. A sample calculation, including both inputs and outputs, is presented. Program listings and operational information related to the programs are given in appendices.

DD FORM 1 JAN 64 1473

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Helicopter						
Rotor						
Rotor Flow Field						
Aerodynamics						
Fluid dynamics						
Digital Computation						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.